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Analysis of programs and procedures designed to mitigate F/A-18 mishaps caused by Out of Control Flight

Steven G. Potter

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To the Graduate Council:

I am submitting herewith a thesis written by Steven G. Potter entitled "Analysis of programs and procedures designed to mitigate F/A-18 mishaps caused by Out of Control Flight." 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:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

To the Graduate Council:

I am submitting herewith a thesis written by Steven G. Potter entitled "Analysis of Programs and Procedures Designed to Mitigate F/A-18 Mishaps Caused by Out-of-Control Flight." I have examined the final paper 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 D. Kimberlin

Dr. Ralph Kimberlin, Major Professor

We have read this thesis
and recommend its acceptance:

U. Peter Solies

Frank G. Collins

Accepted for the Council:

Vice Provost and

Dean of Graduate Studies

Analysis of Programs and Procedures Designed to Mitigate F/A-18 Mishaps Caused by Out of Control Flight

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

Steven G. Potter
December 2001

DEDICATION

This thesis is dedicated to my wife, Lee Ann
for her continuous support and encouragement.

It is further dedicated to my parents, David and Grace,
and my grandparents, Clearance, Grace, Ralph, and Abigail
for supporting my passion for Aerospace Engineering and
providing significant resources for my undergraduate education.

ACKNOWLEDGMENTS

I would like to acknowledge the outstanding engineers (Scott Hoffman, Chris Clark, Bob David, Mike Heller, John Foster, Jessica Wilt, and Bill Facey) and test pilots (MAJ Todd Standard, CDR Kevin Greene, CAPT Charles Everett, and Ricardo Traven) of the Naval Air Warfare Center Aircraft Division, The Boeing Company, and the National Aeronautics and Space Administration for their contributions to this paper and their dedication to the cause of preventing F/A-18 out-of-control flight mishaps.

I would also like to thank LT Matt Bartel of the Naval Safety Center for his assistance with acquiring the data necessary for the quantitative analysis. A debt of gratitude is also owed to the United States Navy, specifically Les Scott and Ron Glockner, for approving the necessary training funds to complete my Master's degree.

ABSTRACT

In 1983 the F/A-18 'Hornet' was introduced into the United States Navy fleet. Since that time, Out-of-Control Flight (OOCF) has been the number three cause of F/A-18 losses, third only to Controlled Flight Into Terrain (CFIT) and midair collisions. To mitigate crashes due to sustained OOCF modes, a pilot training program was developed and new recovery procedures were implemented. Begun in 2000, the Full Aft Stick Recovery Controls flight test program began evaluating alternate recovery procedures for the most common OOCF mode, *falling leaf*. This program resulted in improved OOCF recovery procedures for the fleet and suggested a technique that has the potential of substantially reducing altitude loss. One year later, the Naval Air Systems Command (NAVAIR) Departure Training Program was formally introduced to provide academic lectures, a simulation session, and in-flight OOCF training to F/A-18 fleet pilots. The effectiveness of these programs is attributed to the quality of instructional materials, the hands-on instructional techniques, and the exploration of radically altered emergency procedures. These programs and procedures are likely to substantially reduce the number of aircraft lost to OOCF.

PREFACE

The analyses, opinions, conclusions and recommendations expressed herein are those of the author and do not represent the official position of the Naval Air Warfare Center, the Naval Air Systems Command, or the United States Department of the Navy. The author's recommendations should not be considered attributable to any of the aforementioned authorities or for any purpose other than fulfillment of the thesis requirements. Data and conclusion were gathered from ground and flight tests in support of an official Department of Defense Test and Evaluation project. The author played a significant role in the planning and gathering of both the ground and flight test data. Although the author was the lead project engineer for portions of this government project, this project was not conducted for the purpose of this thesis.

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LIST OF ABBREVIATIONS

ACM	Air Combat Maneuvering
AFU	Auto Flaps Up
ADS	Air Data System
AOA	Angle of Attack
ASA	Accelerometer Sensor Assembly
ASRM	Automatic Spin Recovery Mode
BVR	Beyond Visual Range
CAS	Control Augmentation System
CFIT	Controlled Flight Into Terrain
FAS	Full Aft Stick
FCC	Flight Control Computer
FFS	Full Forward Stick
FMS	Foreign Military Sales
FRS	Fleet Replacement Squadron
HUD	Heads Up Display
KCAS	Knots Calibrated Air Speed
LWS	Light-in-the-seat With Sideforce
MFS	Manned Flight Simulator
MSRM	Manual Spin Recovery Mode
NAVAIR	Naval Air Systems Command
NAWCAD	Naval Air Warfare Center Aircraft Division

NSATS	Naval Strike Aircraft Test Squadron
OOCF	Out-of-Control Flight
PA	Powered Approach
PDG	Post Departure Gyrations
PMA 265	F/A-18 Strike Fighter Program Office
Qc	Compressible Dynamic Pressure
RAG	Replacement Air Group
RSA	Rate Sensor Assembly
RP	Replacement Pilot
SNA	Student Naval Aviator
USNTPS	United States Naval Test Pilot School

CHAPTER I

INTRODUCTION

In January 1976, the McDonnell Douglas Aircraft Corporation won the contract to begin full-scale development of a new, carrier based, multi-role fighter/attack aircraft for the United States Navy and Marine Corps. This advanced weapon system would replace the aging F-4 'Phantom II' fighter and the A-7 'Corsair II' attack aircraft. The new strike fighter was designated as the F/A-18 'Hornet' in March 1977. The first test aircraft made its first flight on November 18, 1978 and the Secretary of Defense approved full production in June 1981. The Hornet entered operational service with the Navy in January 1983.[1]

In addition to its distinctive feature of being a multi-role fighter and attack aircraft with advanced avionics, weapon, and mission systems, the Hornet was also equipped with a sophisticated 'fly-by-wire' flight control system. The flight control system and airframe were designed to provide pilots with exceptional maneuvering capability and precise flying qualities throughout the flight envelope (A description of the F/A-18 airframe and flight control system is presented in Appendix A). These design features enhanced mission effectiveness for both air-to-ground and air-to-air combat scenarios.

Although Beyond Visual Range (BVR) weapons were incorporated into the design of the Hornet, close-in combat with other aircraft remained a possibility due to the existence of sophisticated defensive countermeasure systems onboard most comparable modern fighters. In fact, Air Combat Maneuvering (ACM) strategy and tactics continued to recognize and emphasize the importance of the 'Dog Fight' at the slow speed edge of the flight envelope.[2] Because of this, pilots were taught how to maneuver their aircraft using the unique high angle of attack design features of the Hornet to ensure their best chance for combat victory.

Maneuvering the Hornet safely and accurately at slow speeds however, required special precautions and was not without risk. The edge of the Hornet's slow speed flight envelope was defined by controllability, in that, uncommanded aircraft motion resulted when the dynamic air pressure acting on the flight control surfaces was not sufficient to balance the aerodynamic forces and moments acting on the aircraft. Departure from controlled flight often resulted if the pilot misapplied controls or lost situational awareness with regard to critical flight parameters while maneuvering at very slow speeds. Significant altitude was required to recover from a departure. The flight manual prohibited intentional departures and spins due to the excessive loss of altitude during recovery and therefore, the training squadrons could not expose new Hornet pilots to actual Out-Of-Control Flight (OOCF) conditions. Simulation was employed as the best alternative for pilots to practice recovery procedures, but it had significant limitations when teaching departure avoidance. Because of these facts, the first time a pilot executed the recovery procedures in a dynamic flight environment was following his or her first unintentional departure from controlled flight.

According to the Naval Safety Center, eleven F/A-18 aircraft were lost to a sustained OOCF mode between the Hornet's entrance to operational service in January 1983 and August 2001.[3] Many other hazard reports were written by fleet pilots to document additional OOCF incidents. Analysis of the mishap data did not reveal a particular aircraft configuration (center of gravity, external wing stores, etc.), pilot profile, or aircraft squadron that was responsible for causing the mishaps. For example, mishap pilot experience ranged from 50-1205 hours and there were as many mishaps in the training squadrons as in operational units. The only common trait among all of the mishap pilots was that they all were products of essentially the same training program.

Another significant aspect of the mishap data showed that in several cases, the prescribed recovery procedures were not effective. Data from a recent mishap indicated that after the aircraft departed controlled flight, the pilot executed the appropriate flight manual recovery procedures. This action however, did not result in recovery, and post flight analysis indicates that it may have actually contributed to prolonging and/or exaggerating the departure. Other mishaps and incidents similar to this prompted test pilots and fleet aviators to question the adequacy of the prescribed procedures. For instance, in another mishap, after the pilot applied the prescribed recovery controls, the aircraft did not show any signs of recovery. With little altitude and time left before ejection altitude, the pilot applied controls that were opposite from the approved recovery procedures in a final attempt to recover. The aircraft immediately showed signs of recovery, however, it was too late and the pilot was forced to eject.

In May 2000, the author served as Lead Project Engineer for flight tests that were conducted at the Naval Air Warfare Center Aircraft Division (NAWCAD) to analyze the OOCF falling leaf recovery procedures in an effort to improve recovery characteristics and to reduce overall altitude loss following departure. The flight manual recovery procedures were modified the following month. In March 2001, the Naval Air Systems Command (NAVAIR) also implemented an in-flight, departure training program to address the facts from the analysis of the safety center data. The author currently serves as the Assistant Departure Training Program Manager. This paper documents these programs and procedures and analyzes their effectiveness and potential to prevent F/A-18 mishaps.

CHAPTER II

NAVAL SAFETY CENTER DATA ANALYSIS

Mishap and incident data were obtained from the Naval Safety Center aviation database.[4] Following each F/A-18 accident, a military mishap board was formed to collect and analyze information in an attempt to determine causal factors. Each mishap report contained a summary of the event including pilot actions prior to the mishap, supporting data, and conclusions about what may have caused the accident. Also, Hazard reports were written by fleet pilots to document incidents, potential operational hazards, and lessons learned. Both the mishap and hazard reports, which were sent to all Hornet activities in an effort to disseminate important information to all affected personnel, suggested the need for new programs and procedures.

According to the data, the first Hornet was lost to OOCF during operational testing in November of 1980. The pilot was evaluating defensive basic fighter maneuvers at high angles of attack just prior to departure. The factors contributing to this mishap were determined to be inadequate flight control system design and insufficient test and evaluation of spin/OOCF procedures.[5]

The mishap data presented in figure 1 highlights two distinct accident-prone periods. Six aircraft were lost from May 1989 until May 1993 and five were lost from September 1998 to July 2000. All eleven mishaps were attributed to pilot error, in that, the pilot made improper flight control inputs, failed to recognize impending departure,

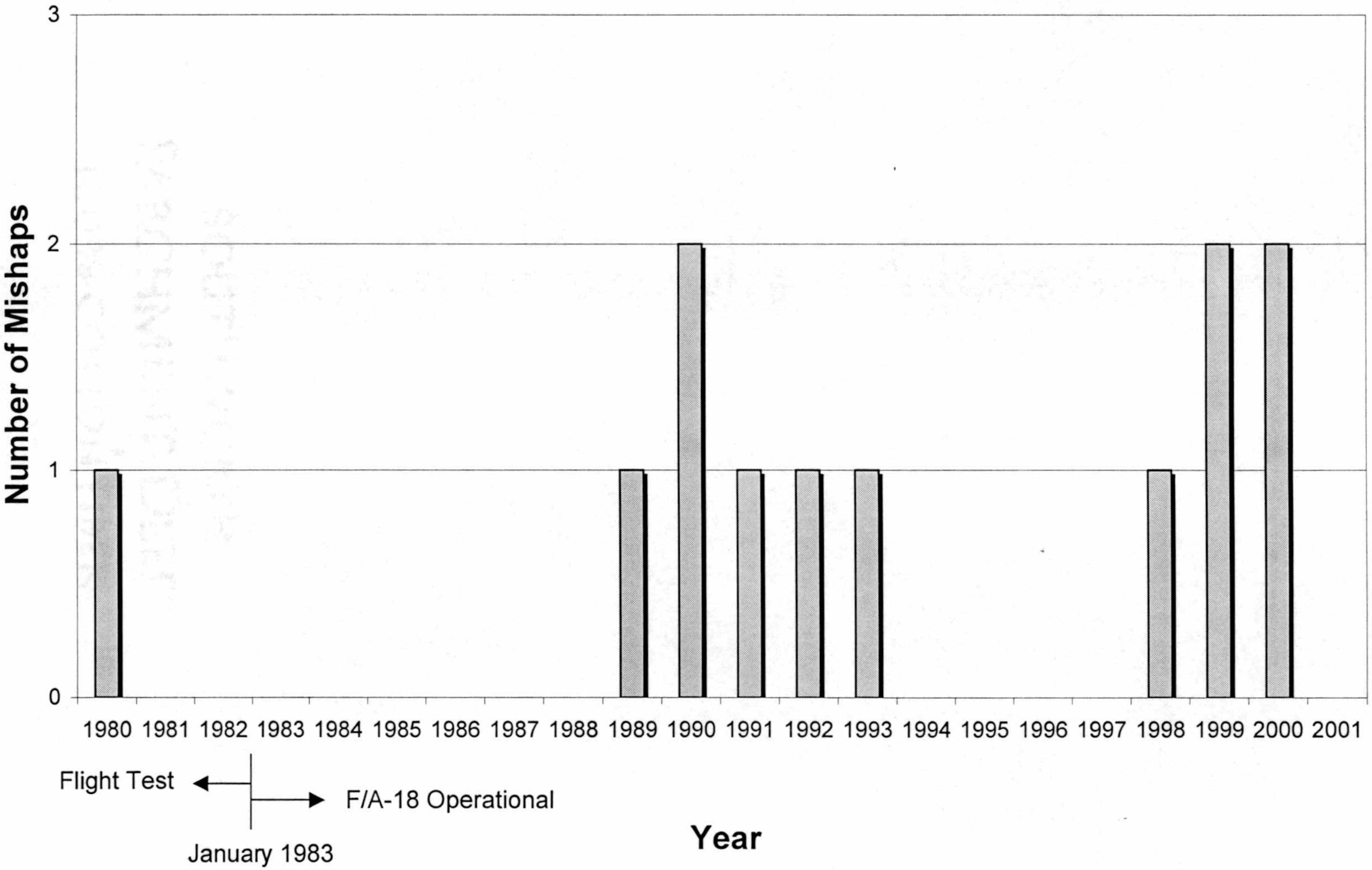
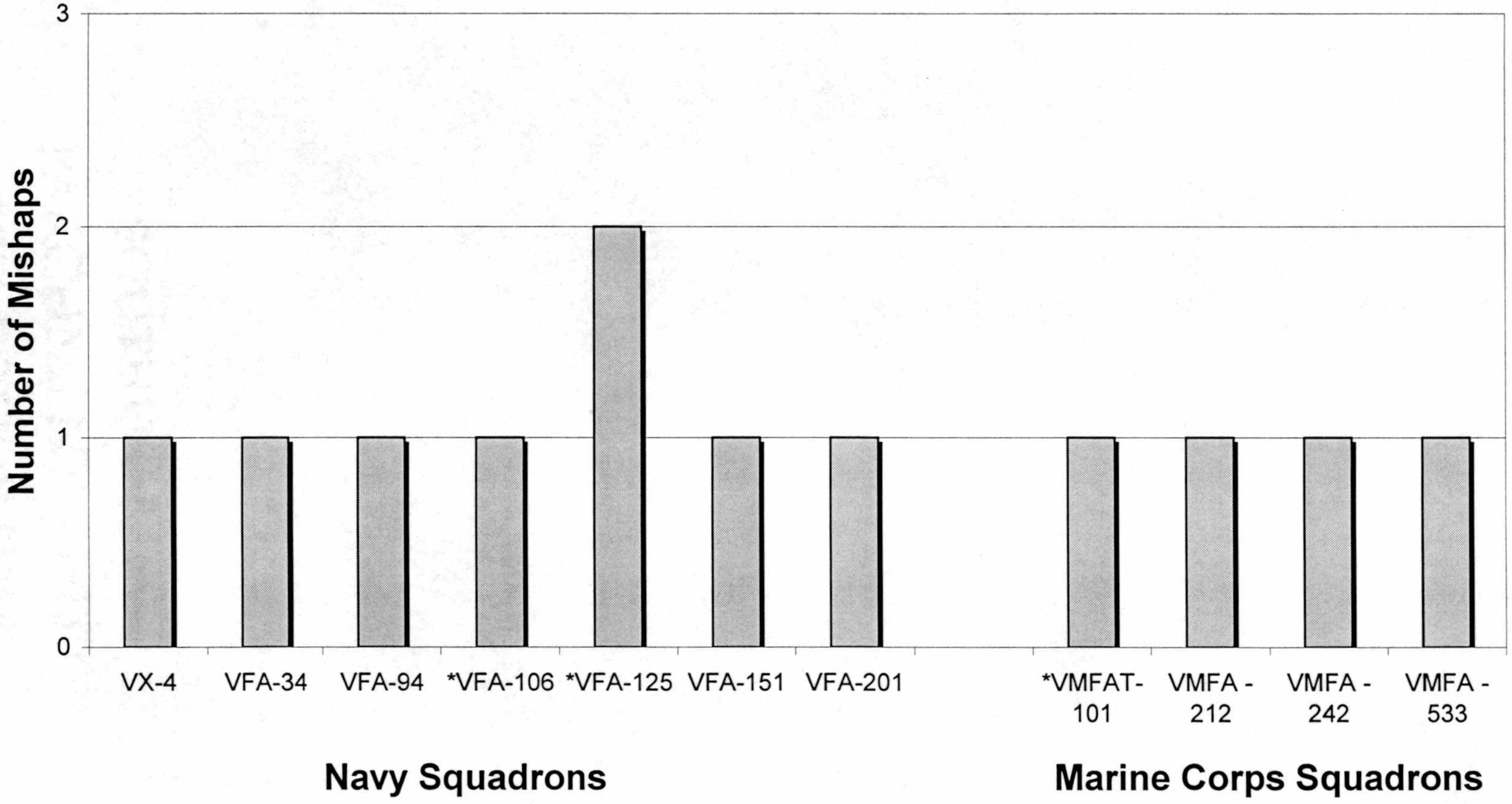


Figure 1. F/A-18 Out-of-Control Flight Mishaps by Year

or failed to properly execute recovery controls.[6] Significant concern was generated throughout the Hornet community after each of the initial six losses during the four-year period from 1989 - 1993. This caused Fleet Commanders and Program Managers to review the F/A-18 training flow and the overall Student Naval Aviator (SNA) syllabus. The F/A-18 program office sponsored several flight test programs in an effort to establish a departure demonstration flight or some other type of training program. Renewed interest in a training program was prompted five years later when five more aircraft were lost to OOCF during the second accident prone period from 1998 - 2000. In each of these five mishap reports, the lack of departure training was specified as a contributing factor.

Figure 2 presents OOCF mishaps attributed to each squadron. Of the twelve mishaps, four occurred in Marine Corps squadrons and seven in Navy squadrons with only one Navy squadron having two OOCF losses. All F/A-18 pilots received their initial training from one of the three Fleet Replacement Squadrons (FRS). Each of the three FRS has experienced at least one mishap, however, these mishaps account for only one third of the total losses. This clearly indicated that squadron specific procedures, tactics, or maintenance practices did not cause OOCF losses and further suggested that the overall pilot training program may be a causal factor.

Figures 3 and 4 present OOCF mishaps by pilot experience. Of the twelve mishaps, pilot flight experience in terms of flight hours was provided in ten of the mishap reports. Pilot experience in type ranged from 50 to 1205 flight hours with an



Notes:
*Training Squadrons

Figure 2. F/A-18 Out-of-Control Flight Mishaps by Squadron

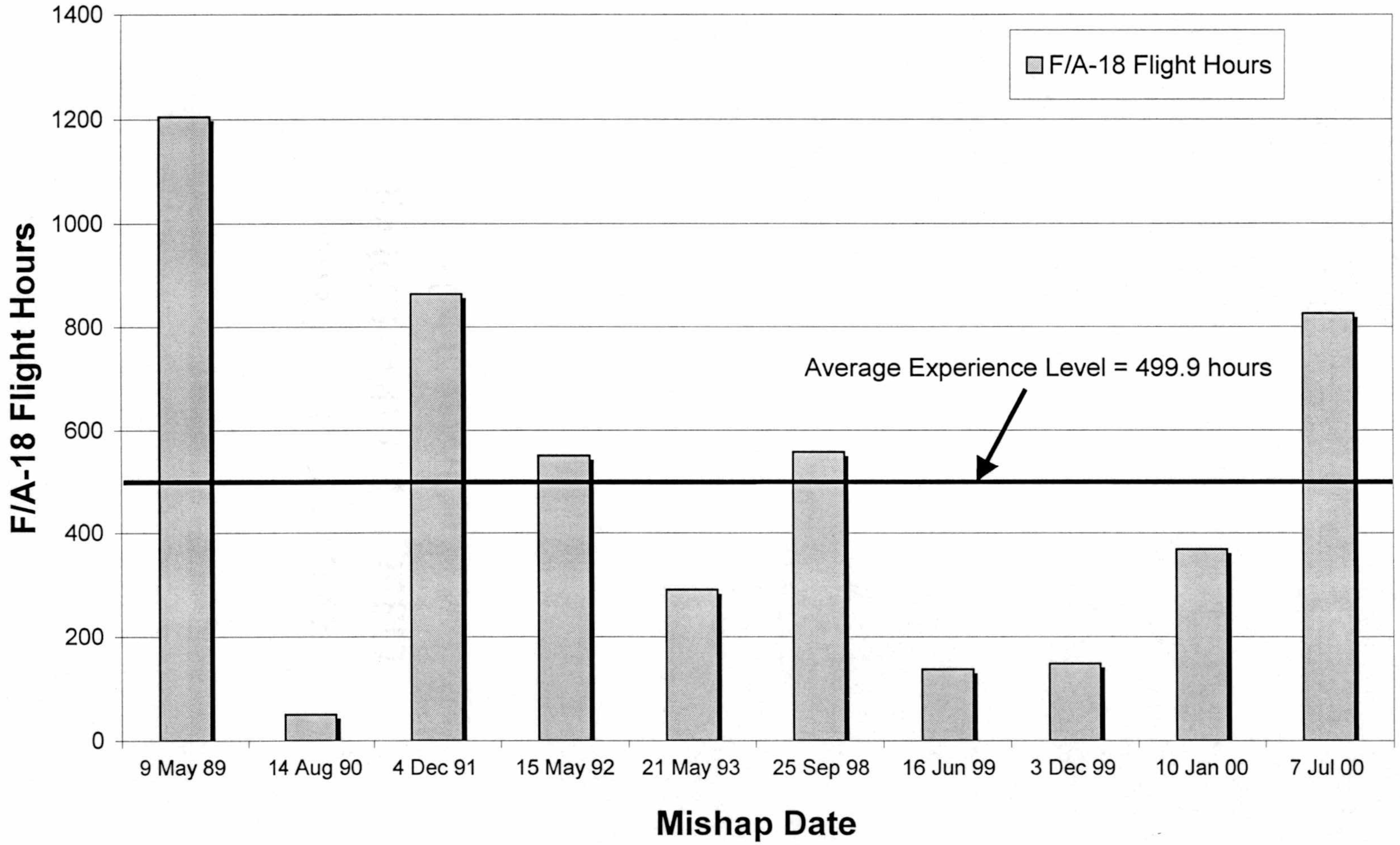


Figure 3. F/A-18 Out-of-Control Flight Mishaps by Pilot Experience in Type

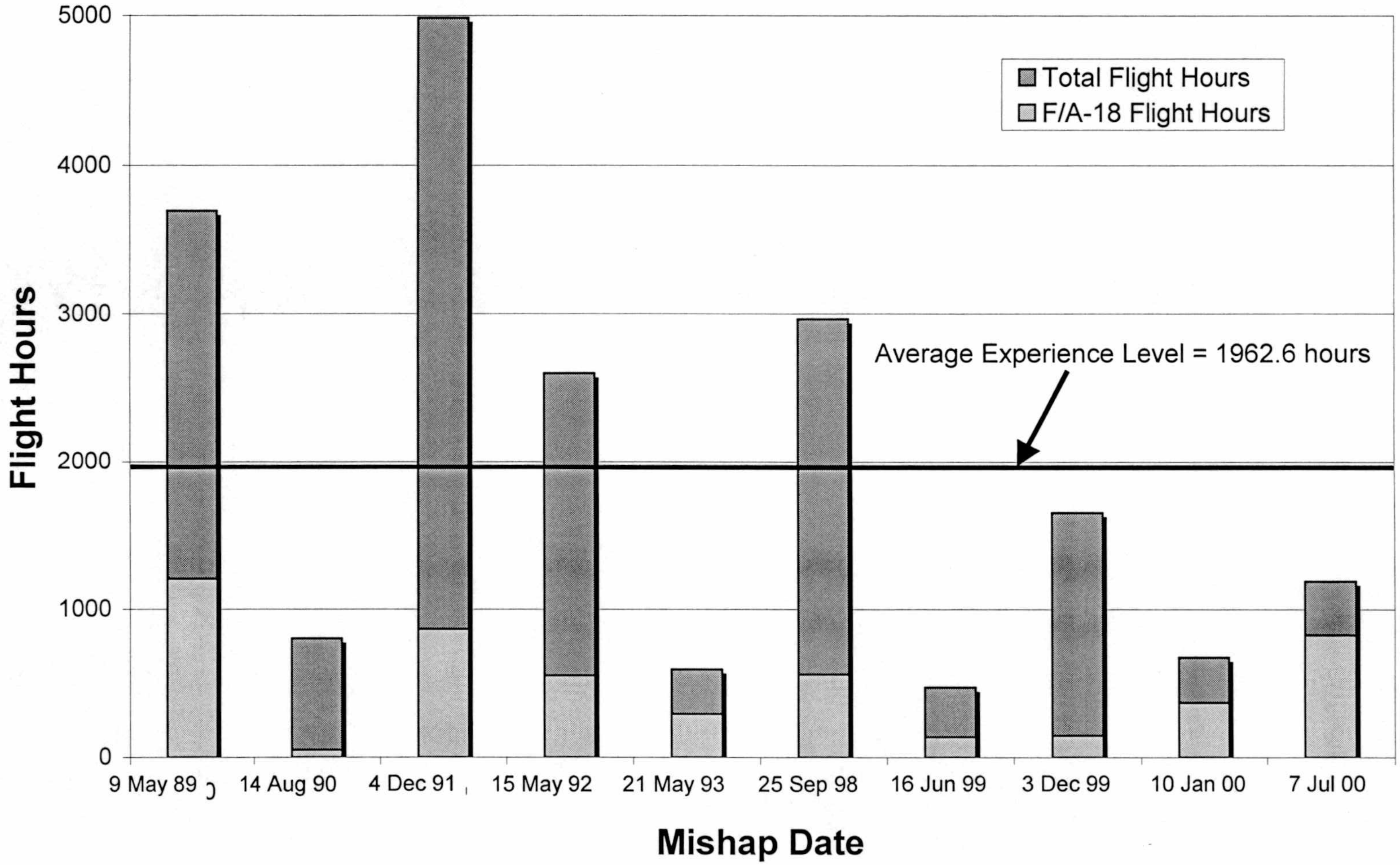


Figure 4. F/A-18 Out-of-Control Flight Mishaps by Overall Pilot Experience

average of 499.9 hours. Overall piloting experience ranged from 302 to 4986 flight hours with an average of 1962.6 hours. This wide range of mishap pilot experience levels did not highlight a particular profile (i.e. inexperienced student) and was not necessarily a factor in causing the OOCF mishaps.

Figure 5 presents OOCF mishaps by model. Seven single seat F/A-18A/C and five two seat F/A-18B/D models were lost. The F/A-18 A and C models share identical outer mold lines as do the F/A-18B and D models. There appeared to be no difference between the various models in causing OOCF mishaps and this data suggested that OOCF accidents could occur in any F/A-18 model.

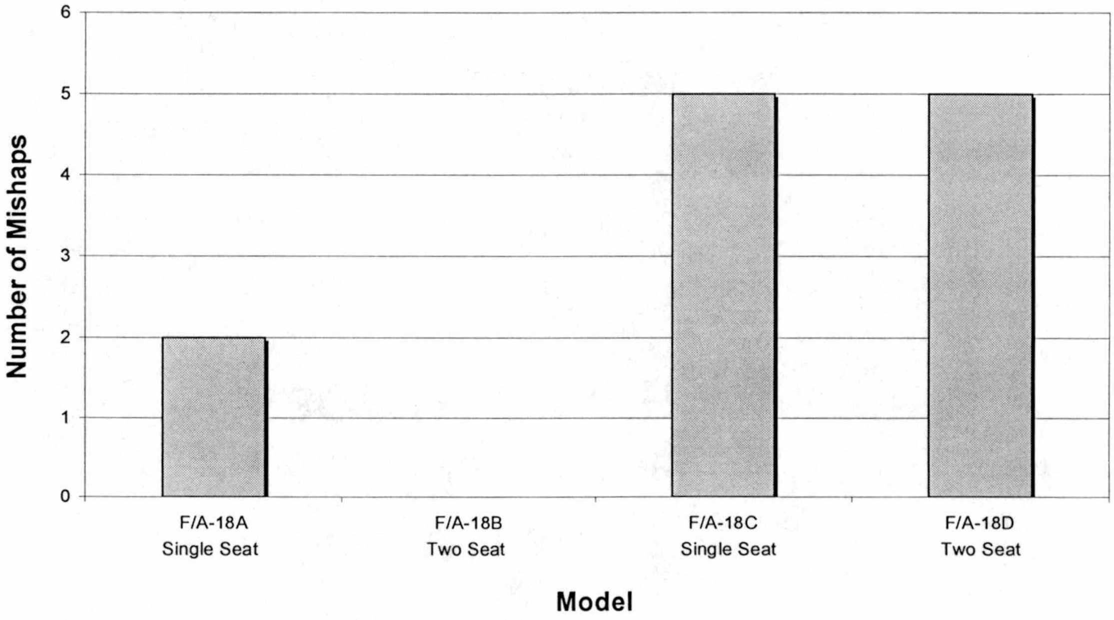


Figure 5. F/A-18 Out-of-Control Flight Mishaps by Model

CHAPTER III

F/A-18 OUT-OF-CONTROL FLIGHT CHARACTERISTICS

The F/A-18 flight control laws were designed to augment the airframe's natural resistance to depart controlled flight or spin without substantially limiting pilot control authority. A typical fleet pilot, however, may have experienced a departure from controlled flight while maneuvering aggressively in certain portions of the flight envelope. The primary factors that contributed to departure susceptibility included aircraft external configuration, center of gravity location, and flight conditions, primarily AOA and sideslip.[7] The departure prone regions of the F/A-18B/D flight envelope are presented in figure 6.

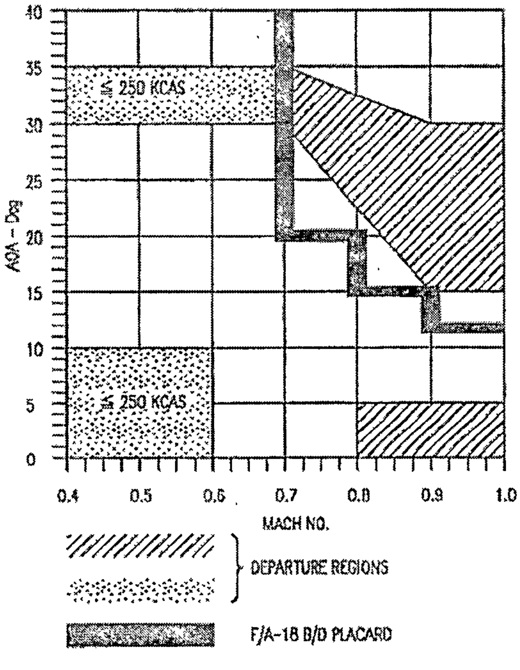


Figure 6. F/A-18 Departure Prone Regions with Centerline External Fuel Tank. Source: NATOPS Flight Manual Navy Model F/A-18A/B/C/D 161353 and up Aircraft, A1-F18AC-NFM-000, change 5, 1999, p. IV-11-8.

According to mishap and hazard reports, departures were usually caused by overaggressive maneuvering or misapplied controls in a departure prone region of the envelope. Overaggressive maneuvering, specifically steep turns at low airspeeds, usually led to a sideslip divergence in which the sideslip angle increased to a point where the directional aerodynamic restoring forces and moments were no longer sufficient to return the aircraft to a trimmed, zero sideslip condition. The resulting motion was typically characterized by a ‘nose-slice yaw divergence’ followed by an uncommanded roll in the same direction.[8] Following the initial motion due to departure, the aircraft may have experienced additional post departure gyrations (PDG). The post departure gyrations could then develop into one of the sustained OOCF modes as indicated in figure 7.

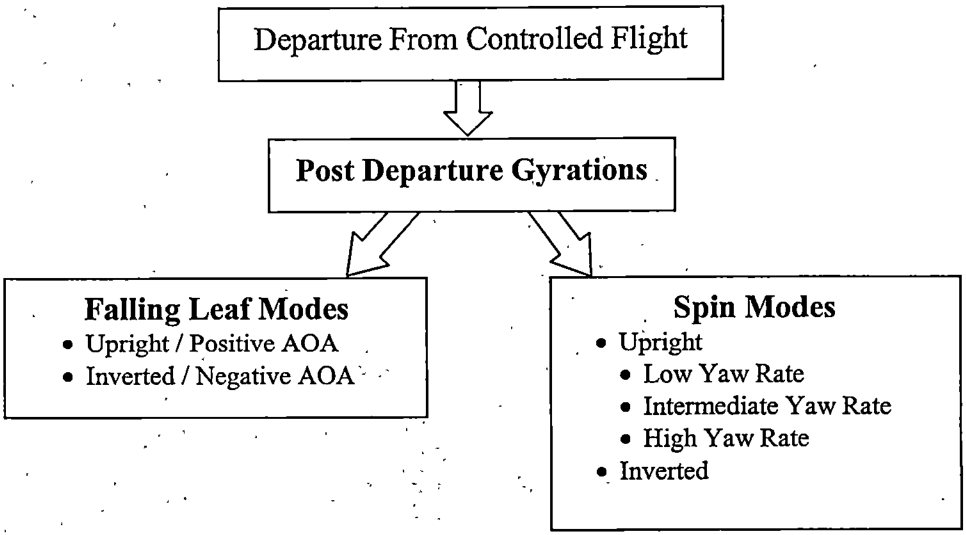


Figure 7. F/A-18 Out-of-Control Flight Modes

Post Departure Gyrations

Post departure gyrations followed most departures and were described in the flight manual as random changes in AOA and airspeed and were frequently accompanied by side forces.[9] Recovery from PDG was generally prompt provided that the pilot released all controls. Releasing the controls allowed the flight control system to efficiently generate appropriate control surface commands necessary for recovery. Flight tests indicated that pilots who attempted to apply control inputs during post departure gyrations often aggravated the PDG motion, which resulted in delaying recovery.[10, 11] Occasionally, PDG motion progressed into a fully sustained OOCF mode. The Hornet exhibited two primary sustained OOCF modes: Falling Leaf and Spins.

Falling Leaf Mode

Of the two primary sustained OOCF modes, the upright/positive AOA falling leaf was the most common mode and was attributed to the majority of OOCF mishaps. In most cases, this mode was entered following PDG motion after the aircraft departed as a result of uncoordinated maneuvering at low speeds and an excessive nose high pitch attitude. The low airspeed flight conditions did not provide sufficient control power to manage the rapid buildup of AOA and sideslip. Positive AOA falling leaf motion was defined in the flight manual as repeated cycles of large uncommanded roll/yaw motion accompanied by high side force and near zero g cues at each reversal.[12] Theses indications were also know to aircrew as "Light-in-the-seat With Sideforce"

(LWS) cues.[13] Entry into the inverted falling leaf mode was highly unlikely, however, the mode was first identified during flight tests executed in 1992.[14]

Research to date by the Navy, NASA, Boeing (formerly McDonnell Douglas Aircraft), and other contractors has shown that the upright falling leaf is an unstable Dutch roll mode that is characterized by in-phase roll and yaw oscillations. The F/A-18 has been susceptible to this mode due to apparent relaxed static directional stability at high angles of attack.[15] A time history of the pitch, roll, and yaw rates from typical falling leaf motion captured during a May 2000 OOCF flight test is presented in figure 8. In figure 8, the roll and yaw rate peaks are shown to be in-phase, with the peak pitch rate lagging the roll/yaw rates by approximately 90° phase angle. The sustained motions described in figure 8 were the result of coupling dynamics, specifically inertia pitch coupling. In this case, inertia pitch coupling was generated by the product of the roll and yaw rates. Heller analyzed the data and showed that the relative inertia pitch coupling contributions were significant when compared to the aerodynamic pitching moments at those flight conditions.[16]

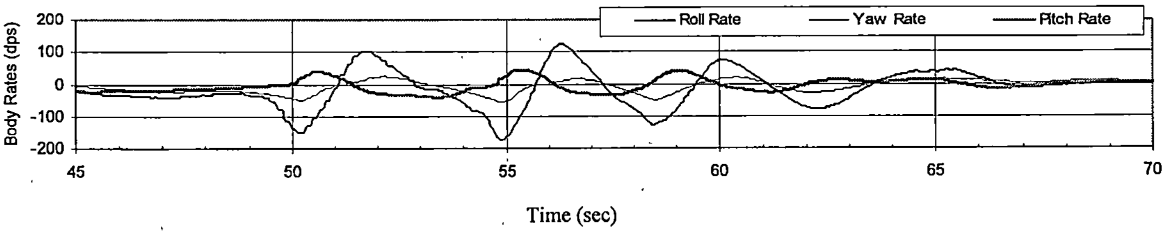


Figure 8. F/A-18 Falling Leaf Motion

Recovery from the falling leaf mode took time and therefore, significant altitude because the amount of nose down pitch control power available for recovery was low compared to the strong nose up tendency caused by inertia pitch coupling. The flight manual specified that extraordinary patience was required and recovery might take from 8,000 to 12,000 ft.[17] The specific flight manual recovery procedures and suggestions for alternate recovery procedures to reduce altitude loss are discussed in chapter 5.

Spin Mode

Spins were the least common mode of sustained OOCF and rarely occurred when the aircraft was symmetrically loaded. However, the existence of a lateral weight asymmetry, as was fairly common during normal fleet operations, decreased departure resistance and was the most likely cause for entering a spin following a departure. The F/A-18 had two spin modes, upright and inverted. Entering the inverted spin mode was highly unlikely. The upright spins were further divided into three modes: low yaw rate, intermediate yaw rate, and high yaw rate.

Flight tests showed that recovery from any of the spin modes was quick provided that the proper anti-spin controls were applied after the pilot had positively confirmed the spin mode.[18] The normal flight control laws limited the control surface deflections of the ailerons and differential stabilators at high AOA to reduce the substantial and undesirable effects of adverse yaw at very slow speeds. Therefore, if a spin developed following a departure, the normal control laws were not able to recover from the spin conditions due to reduced control surface authority. In order to recover from spins, the F/A-18 employed an Automatic Spin Recovery Mode (ASRM) that detected spin flight conditions, informed the pilot by displaying a large anti-spin command arrow on the cockpit displays as depicted in figure 9, and provided full control surface authority once the pilot applied the proper recovery controls. This feature enabled recovery from a spin usually within two revolutions for any of the OOCF spin modes. Further details of the ASRM flight control laws are described in appendix A.

Radome and Flight Control Surface Rigging Effects on Departure

In addition to overaggressive maneuvering and misapplied controls, several other physical aircraft properties had the potential of causing unwanted sideslip. First,

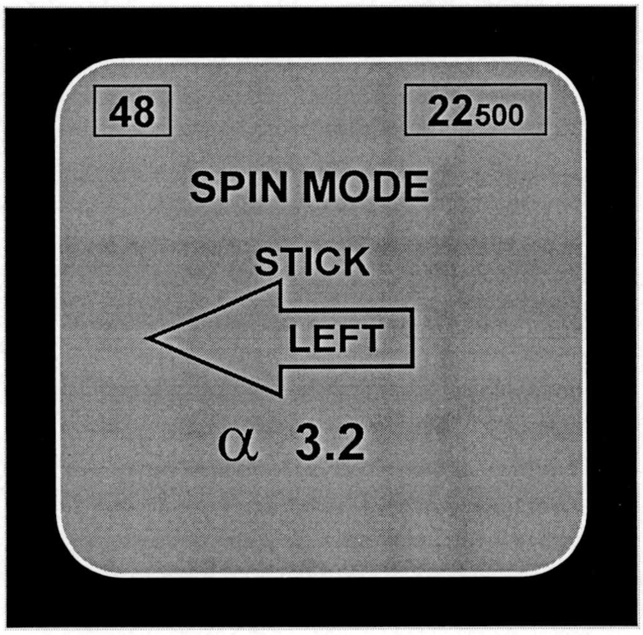


Figure 9. Automatic Spin Recovery Mode Cockpit Display

vortices were created and shed from either side of the F/A-18 nose cone (radome) just as a vortex is formed at each wingtip due to unequal pressures above and below the wing. If the fore body vortices separated asymmetrically or the separation characteristics varied from one side to the other, an unbalanced side force was created at the radome that caused a yaw acceleration about the aircraft center of gravity.[19] This effect was significantly enhanced and was usually only a problem at very high angles of attack (> 35°). An out of round radome due to the manufacturing process or small imperfections caused by sloppy nick/dent repair marks in the first 12 inches of the radome have significant effects on vortex shedding. Ensuring that the radome was repaired to within maintenance limits and verifying symmetric shedding under controlled conditions (power off, full aft stick stall and accelerated stalls) considerably reduced the likelihood of unintentional departure.

Mis-rigged flight control surfaces also caused uncommanded rolling moments and undesirable sideslip. Trimming the aircraft laterally minimized the effects of mis-rigged surfaces during operations in the heart of the flight envelope. However, at very high angles of attack the resulting uneven flight control surfaces had the potential of causing yawing moments due to differences in drag characteristics and therefore could contribute to sideslip buildup. Ensuring that all surfaces were rigged according to the prescribed maintenance procedures helped to reduce the likelihood of unintentional departure.[20]

Out-of-Control Flight Prevention

The F/A-18 flight control system design included control laws that provided departure resistance in departure prone regions of the flight envelope. Specific control laws were also incorporated to detect a spin and automatically reconfigure the control laws to assist the pilot with recovery. Preventing unintentional departures, however, required the pilot to know the departure prone regions of the flight envelope, the aircraft flight limits (airspeed, AOA, etc.), and most importantly the impending departure cues. The pilot also had to recognize when the aircraft was not properly responding to control inputs (departure) and subsequently how to identify PDG motion and the specific OOCF modes in order to execute the appropriate recovery procedures. Studying and memorizing the flight manual provided some of the required knowledge, however, other critical information was best obtained in the cockpit environment.

Several natural and man-made cues were available to assist the pilot with departure avoidance. First, the flight control system provided aural warning tones for both AOA and yaw rate. The steady AOA tone was annunciated above 33° and below -7° AOA while the oscillating yaw rate tone began when rates exceeded 25 degrees per second in either direction. If both conditions were present, the AOA tone had priority.[21] Second, the heads up display (HUD) graphically presented the aircrafts velocity vector using an airplane symbol as depicted in figure 10. The relative position of velocity vector symbol provided the pilot with an indication of AOA and sideslip. A digital readout of AOA was also presented on the display. The natural cues consisted of relative silence in the cockpit, an indication of very slow airspeed/high AOA, and a "vortex rumble" cue. Vortex rumble occurred when sideslip was so excessive that the fore body vortices impinged on or just above the canopy as illustrated in figure 11. These natural aural cues were often not known to pilots or not noticed by pilots immersed in flying tasks.

Proper identification of the OOCF mode and application of the appropriate control inputs were critical to the recovery of the aircraft. Even though there were only two primary sustained OOCF modes, distinguishing between the sustained modes and the random PDG motion was very confusing to pilots. Adding the physical and mental stressors associated with the dynamic cockpit environment only compounded the problem of OOCF modal identification and recovery.

For sustained spins, the ASRM command arrow was displayed to assist the pilot with the proper application of recovery controls. Unfortunately, the falling leaf mode often produced intermittent command arrows since the yaw rate criteria were briefly satisfied to drive the arrow and therefore would falsely identify a spin condition. Also, the yaw rate associated with a falling leaf may be biased to one direction as shown in F/A-18 simulator data presented in figure 12. This falling leaf characteristic has been described by several studies as a highly oscillatory, low yaw rate spin.[22] Control law updates were incorporated in 1984 to reduce the occurrence of the intermittent command arrows, however, this problem was not completely eliminated. According to several hazard reports, pilots have improperly 'chased' the spin arrows and subsequently aggravated or delayed recovery.

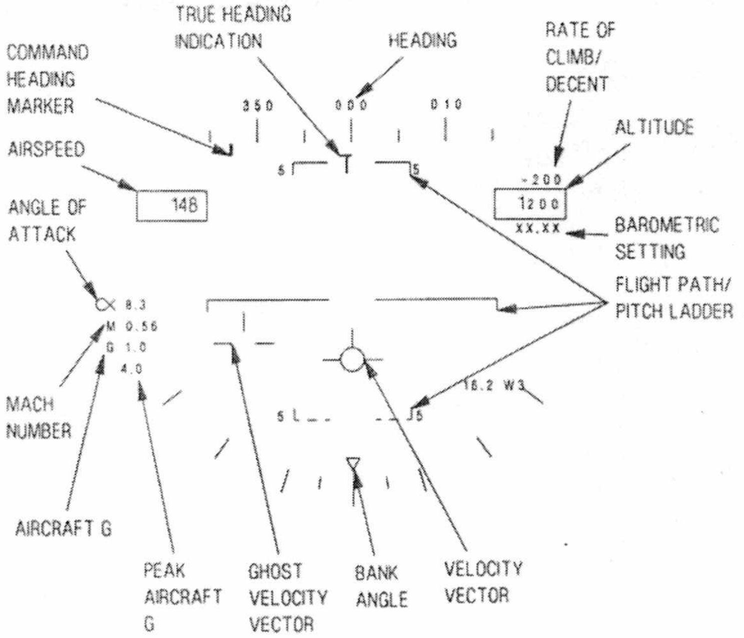


Figure 10. F/A-18 Heads Up Display Symbology.
Source: NATOPS Flight Manual Navy Model F/A-18A/B/C/D 161353 and up Aircraft, A1-F18AC-NFM-000, change 5, 1999.

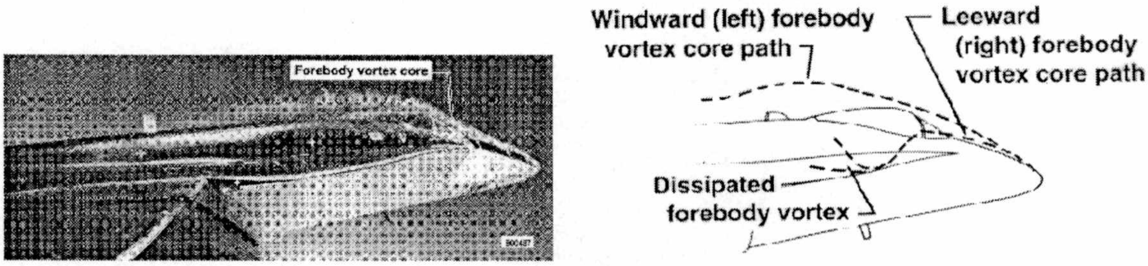


Figure 11. Fore body Vortices Interacting with F/A-18A Canopy (β = 5º)
Source: Bjarke, Lisa J., Del Frate, John H., Fisher, David F., *A Summary of the Forebody High-Angle-of-Attach Aerodynamics Research on the F-18 and the X-29A Aircraft*, NASA TM 104261, November, 1992

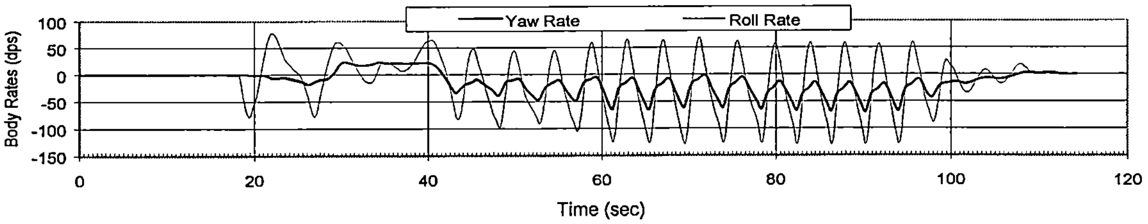


Figure 12. Falling Leaf Motion / Oscillatory Low Yaw Rate Spin

Transferring the required departure prevention knowledge to pilots safely and effectively required a structured, multi-faceted approach. The limitations of classroom and simulator training prevented students from experiencing the physical aspects of impending departure cues, the unique and potentially disorienting motion associated with each OOCF mode, and the associated stressors in the cockpit environment. A pilot training program that combined departure avoidance with departure recovery was needed to reduce the number of F/A-18 mishaps.

CHAPTER IV

F/A-18 FLEET DEPARTURE TRAINING PROGRAM

Introduction

The Naval Safety Center data and the nature of the OOCF characteristics led to six years of flight test and analysis by NAWCAD test pilots and engineers and resulted in the F/A-18 Fleet Departure Training Program being officially established in March 2001. The Naval Strike Aircraft Test Squadron (NSATS) had been conducting departure flight-testing and several demonstration flights for Navy pilots and Foreign Military Sales (FMS) customers since 1994. The United States Naval Test Pilot School (USNTPS) was requested by F/A-18 Strike Fighter Program Office (PMA-265) to develop, through cooperation with NSATS, a formal training program to provide F/A-18 fleet pilots exposure to high angle of attack flying qualities, departure modes, and recovery procedures. The first fleet instructors were trained in March 2001.

The need for a formal training program was realized during the 1990s, following the loss of twelve aircraft to OOCF. Most of the mishap reports cited insufficient OOCF training as a contributing factor, and if fact, the only common trait among all of the data was that each mishap pilot was a product of essentially the same training program. As a result, there was a growing concern that fleet F/A-18 pilots did not have a thorough understanding of high angle of attack and departure characteristics nor experience in departure mode recognition and recovery. This prompted Navy management to take a closer look at how student naval aviators were trained to handle departures and OOCF, specifically those flying the F/A-18.

Student Naval Aviator Training Flow

A student naval aviator began flight training on the ground with a series of academic sessions and pilot ground school. The first instructional flights were given in the T-34B 'Mentor', a single engine, low wing aircraft with a two-seat tandem configuration. The primary focus was on basic air work and flight training included taxi, takeoff, climbs, turns, navigation, stalls, descents, and landings. The student then progressed to the T-34C, a turboprop version of the Mentor that exposed students to more sophisticated systems and advanced maneuvers. Also emphasized during this training phase were stalls and departure avoidance. The T-34B and C platforms permit out of control flight. The instructor demonstrated one or two spins during this time frame. Each pilot acquired a total of approximately 75 flight hours including both instructional and solo flight.

Following T-34C primary training, the SNA advanced to the T-2 'Buckeye', a twin engine jet aircraft that was introduced in 1958. Flight training maneuvers progressed to aerobatics and formation flight. This platform provided the students first exposure to aircraft carrier operations including arrested landings and catapult takeoffs. The T-2 provided excellent spin characteristics for training and allowed the SNA to experience upright spins. Again, stalls were practiced and spins were demonstrated with instructors only, never during solo flights. By this point in the training flow, the typical SNA had acquired approximately 150 flight hours of which, approximately three sorties were dedicated to OOCF training.

With the elimination of the A-4 ‘Skyhawk’ advanced trainer and the planned retirement of the aging T-2 buckeye in 2003, the Navy procured the T-45 ‘Goshawk’ in 1992 to fulfill the advanced training mission. This single engine jet aircraft was designed by British Aerospace as the Hawk and was highly modified to handle aircraft carrier operations by Boeing (formally McDonnell Aircraft Corp). Unfortunately, the T-45 exhibited poor OOCF characteristics and therefore could not be used to adequately train OOCF recovery procedures. Of the operational training squadrons in September 2001, only one still employed the T-2, and therefore the majority of students were trained in the T-45. Those who were trained in the T-45 had not experienced OOCF since very early in their aviation career.

After being selected for fighter/attack aircraft, the SNA proceeded to one of three Replacement Air Group (RAG) squadrons as a Replacement Pilot (RP) for specific F/A-18 training. Training focused on aircraft and weapon systems, air-to-air and air-to-ground combat tactics and maneuvers necessary to accomplish specific missions. The sophisticated F/A-18 was also prohibited from executing intentional departures and spins, and therefore, ground based simulator training was utilized to practice recovery procedures. F/A-18 replacement pilots acquired approximately 120 hours in the F/A-18 prior to assignment to an operational squadron. After completing the entire SNA training syllabus from T-34B to F/A-18, average pilots with approximately 350 total flight hours had experienced on average less than five sorties of airborne OOCF training.

Departure Demonstration Flight Development

In response to the first four OOCF accidents from 1989 to 1991, the F/A-18 program office supported flight tests to investigate and propose maneuvers for a ‘departure demonstration’ flight for new and experienced fleet Hornet pilots. Test pilots and engineers reviewed data from early F/A-18 high AOA flight tests and selected several control inputs for evaluation. Flight tests were executed in 1992 to determine the repeatability of the recoveries from the selected maneuvers that included aggravated and/or cross-controlled inputs to induce departure from controlled flight. The test team concluded that the aggravated and cross-controlled maneuvers were not suitable for a demonstration flight due to the unpredictability of departure duration.

Following two more OOCF mishaps, additional flight tests were conducted in 1994 to study pilot cues associated with departure prevention and avoidance. The test team documented the cockpit indications associated with impending departure, PDG motion, and the OOCF modes. A ‘light-in-the-seat’ with sideforce cue was quantified as a result of this research.[23] Test pilots and engineers also continued the development of several candidate ‘mission representative’ maneuvers for the proposed departure demonstration flight. This time, the maneuvers and flight conditions, such as low airspeed with nose high pitch attitude, were determined from mishap and hazard reports as the most likely to cause OOCF in the typical fleet environment. This new approach addressed all phases of OOCF training including flight at high AOA, pilot recognition of impending departure cues, actual flight demonstration of post departure gyrations, low yaw rate spins, sideslip divergence departures, and the execution of recovery procedures.

From 1994-2000, the departure demonstration flight was flown only at the Strike Aircraft Test Squadron with experienced test pilots at the controls. The flight profile was executed as a test flight under the strict control of a test plan. The test plan outlined the specific aircraft configuration, maneuver entry conditions, safety precautions, unique procedures, and risk mitigation such as aircraft preflight and pre-maneuver checks. Unlike typical fleet operations, all departure demonstration maneuvers utilized a unique 'Controls Released' recovery procedure and all were executed at very high altitudes; in fact, all intentional departures were executed at or above 35,000 feet. Recovery characteristics from the intentional departures usually included post departure gyrations and falling leaf type motion although some recovered with very little motion at all. Recovery duration was random and occasionally required up to 12,000 feet as was seen in earlier testing.

As the test community developed confidence in the flight maneuvers and recovery characteristics, occasional demonstrations were given to fleet pilots and foreign military customers who had purchased the F/A-18. The air forces from Finland and Switzerland immediately realized the benefits of the demonstration flight and requested training for their instructor pilots. By January 2000, the departure demonstration flights had accumulated over 2000 intentional departures with each recovery occurring above 20,000 feet using a controls released procedure.

Fleet Departure Training Program Development

A formal proposal to add the departure demonstration flight to the FRS training syllabus for F/A-18 replacement pilots under instruction occurred in 1997. Prior to its implementation, however, the suggested training maneuvers had to be evaluated for aggravated control inputs during maneuver entry and recovery to ensure adequate safety margins. The aggravated input test program was conducted in 1998 to test the maneuvers and recoveries for sensitivity to mis-applied control inputs. The results from this test program ensured that only the maneuvers tolerant of control input variation were incorporated into the training program.[24]

In the late Fall of 1999, after three more OOCF mishaps and meetings with Fleet Commanders, the F/A-18 Strike Fighter Program Office (PMA-265) requested that the United States Naval Test Pilot School and the Naval Strike Aircraft Test Squadron finalize development of the training program to improve pilot awareness and understanding of impending departure cues and to provide exposure to high angle of attack flying qualities, departure modes, and recovery procedures. A team was formed to convert the existing test plan and demonstration flight into a formal departure training program.

As of September 2001, the Fleet Departure Training Program is in place and consists of three separate training phases. First, the students receive ground training in the form of several technical briefings on F/A-18A/B/C/D high angle of attack flying qualities and departure flight characteristics. Second, a simulator session exposes the student to the specific training maneuvers and cockpit procedures required for the flight-training phase. Departure recognition cues and recovery procedures are also be discussed and reviewed. The final phase of the training is comprised of a high AOA/departure training syllabus flight.

The ground training material includes a one-hour video created by NAVAIR engineers and test pilots that describes the important aspects of F/A-18 stability and control. Actual on-board video from fleet aircraft departures and test flights set the stage for discussion of departure avoidance and recovery procedures. Other ground training material is provided by a qualified instructor and includes presentations on the significant features of the flight control system, high angle of attack flying qualities, and essential pre-flight checks of the aircraft radome and flight control surface rigging. The ground training concludes with a review of the specific flight maneuvers and procedures.

Following the ground training, each student receives a simulator session to discuss impending departure cues and departure characteristics. The specific flight maneuvers, recovery procedures, and emergency procedures are also reviewed and practiced during this time (The simulator session briefing guide is presented in appendix B). Even though the typical fleet simulator provides a high fidelity cockpit environment for practicing procedures, it does not adequately simulate the forces and motions experienced during OOCF or the buffet vibrations, control sluggishness, or vortex rumble cues that are commonly felt prior to departure.

The training is completed with controlled exposure to actual high angle of attack (AOA) and departed flight conditions in an F/A-18B/D aircraft with a qualified instructor in the aft seat. The flight is divided into three phases. First, the student examines the high AOA handling qualities and flight control characteristics while concurrently evaluating the aircraft radome to ensure suitability for intentional departures. Accelerated stalls and flight controls surface rigging checks are also completed during the first portion of the flight.

Next, the student executes a controlled, low yaw rate spin using asymmetric thrust while applying full aft stick to stall the aircraft. This maneuver allows the student to interact with the spin recovery mode control laws, including the command arrows, and to practice the spin recovery procedures. The student is encouraged to recognize the importance of smoothly neutralizing controls once the yaw rate stops based on the out-the-window cues vice the spin command arrow, which may be delayed, to avoid entering a spin in the opposite direction. This maneuver is considered to be controlled flight since the pilot is positively controlling the aircraft throughout the entire maneuver.

The instructor pilot then demonstrates the first intentional departure from controlled flight. The maneuver simulates an overaggressive or misapplied control input during a rudder reversal or 'bug out' maneuver. Full rudder deflection is applied from a wings level attitude at 200 knots calibrated airspeed (KCAS), 0°-5° AOA, and 35,000 feet pressure altitude. This sideslip divergence departure exposes students to the vortex rumble cue just prior to departure and the strong sideforce cues during the initial motion. The maneuver usually produces disorienting rolling and pitching PDG motion and provides initial experience with analyzing flight conditions and departure mode recognition prior to recovery.

The final series of departures include zero airspeed tail slides and 100 KCAS vertical recoveries. Each maneuver begins at 300 KCAS and 30,000 feet. The student initiates a 3g pull to an 80° - 90° nose high attitude and releases the controls once the aircraft ceases to respond to control inputs. Peak altitude ranges from 37,000 – 40,000 feet during these maneuvers. The 100 KCAS vertical recoveries are initiated from the same conditions as the tailslide, however, as airspeed decelerates to 100 KCAS, aft or forward control inputs are applied in an attempt to recover from the nose high situation. A departure from controlled flight results approximately 90% of the time. Typically, PDG motion exhibits random characteristics from these types of nose high departures and frequently includes several cycles of falling leaf type motion. This motion exposes students to the light-in-the-seat with sideforce cues and provides additional experience with positively identifying the appropriate OOCF mode. Occasionally, the falling leaf mode will drive intermittent spin command arrows that will cycle from left to right.

This type of motion forces the student to combine all the available information including the out-the-window view, the flight conditions, and the command arrow to determine the appropriate OOCF mode and recovery procedures. A complete flight briefing guide is presented in appendix B.

CHAPTER V

OUT-OF-CONTROL FLIGHT RECOVERY PROCEDURES

Background

One significant aspect of the Naval Safety Center data revealed that the prescribed recovery procedures were ineffective. Recently, an F/A-18 crashed following a departure during a simulated air-to-air engagement. The aircrew successfully ejected at 6,000 ft above ground level. Data from the mishap aircraft was recovered from the on-board deployable flight incident recorder system and is presented in figure 13.

The data shows the aircraft departed controlled flight from a nose high attitude with near zero airspeed at 56 seconds into the time history as indicated by the right roll rate with a left stick command. The pilot recognized the departure and released all controls as prescribed by the emergency flight procedures only three seconds later at 59 seconds. Controls are released for 19 seconds as PDG motion developed and progressed into the sustained falling leaf mode as indicated by the in-phase roll/yaw rates. The pilot properly identified the upright falling leaf mode and promptly applied and held the prescribed full forward stick (FFS) recovery control input. This control input alarmingly appears to have had <u>no effect</u> on recovery trends and actually seemed to aggravate the motion as indicated by the increasing roll and yaw rates at 84 and 88 seconds. The motion briefly appeared to change for the better at 92 seconds with decreasing AOA and reduced yaw rate, but was followed by another abrupt departure

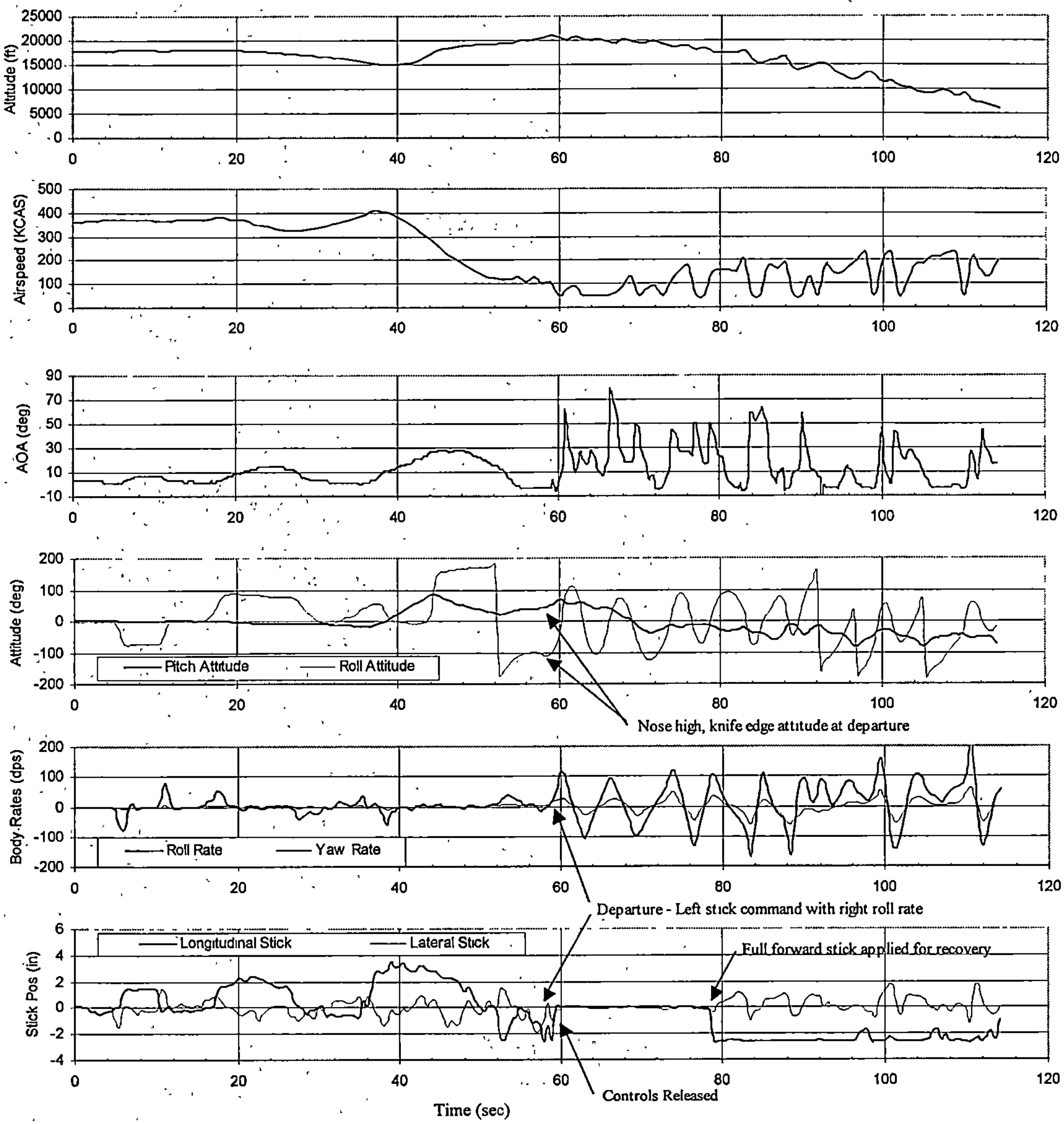


Figure 13 - Falling Leaf Mishap Data

at 98 seconds. The data also showed that throughout this event, all flight controls surfaces were responding properly to the flight control law commands and that no flight control anomalies were present.

At the time of this mishap, the emergency procedures for recovery from an upright falling leaf instructed the pilot to apply full forward stick once the mode had been verified and hold the input until recovery was indicated as defined by AOA and yaw rate cockpit tones removed, side forces subsided, and airspeed increasing above 180 KCAS.[25] This recovery procedure was not developed from flight test data since the sustained falling leaf mode was never documented during initial developmental flight testing. It was formulated based on simulations and engineering analysis with the thought that the falling leaf was similar to a deep stall mode or a "high alpha hang-up." Applying forward stick to reduce AOA was the logical response to recover from this condition and this action was subsequently incorporated into the flight manual procedures.[26]

Other mishaps and incidents similar to this event generated a feeling among fleet aviators and experienced test pilots that the full forward stick falling leaf recovery procedures were inadequate. For instance, analysis of a different mishap showed that after the pilot applied full forward stick the aircraft appeared to be slowly recovering from an upright falling leaf, but the pilot felt that recovery was not proceeding fast enough. The pilot then applied full aft stick (FAS) in a last ditch attempt to recover. According to the report, the aircraft immediately showed signs of recovery including a reduction in the severity of the roll/yaw motion, however, it was too late and the pilot was forced to eject. Excerpts from five other mishap and hazard reports from 1991 to 1997, presented in figure 14, clearly indicated similar conclusions in which FFS failed to recover the aircraft or showed signs that the falling motion was aggravated due to the application of FFS. While several other hazard reports from 1991-1997 indicated that applying FFS affected recovery, no data was available to study and determine the factors responsible for recovery.

Falling Leaf Research

Engineers from several organizations conducted detailed studies of the falling leaf mode between 1992-1996. In 1992, McNamara et. al. from the NAWCAD conducted a flight test program to determine the effects of releasing all controls (as opposed to neutralizing the controls) immediately following a departure. Results from the flight test program were incorporated into the flight manual departure recovery procedures in 1993. The program did not address the recovery procedures for any of the sustained OOCF modes, however, it was the first program to document a repeatable falling leaf mode. The test team concluded that falling leaf motion was sustained by combination of aerodynamic and inertia pitch coupling. Although recovery from a falling leaf motion was obtained with controls released, the team recommended that the existing FFS falling leaf recovery procedures be retained to expedite recovery.[27]

"MISHAP PILOT ATTEMPTED RECOVERY (using full forward stick), BUT MISHAP AIRCRAFT REMAINED UNCONTROLLABLE."

"FULL FWD STICK WAS APPLIED WHICH SEEMED TO MAKE PITCHING MOVEMENTS MORE VIOLENT, SO STICK WAS RETURNED TO NEUTRAL"

"AT APPROX 20,000 FT AGL PILOT APPLIED FULL FWD STICK LEAVING THROTTLES AT IDLE. FULL FWD WAS HELD FOR 45 SECONDS WITH NO APPARENT SIGNS OF AIRCRAFT RECOVERY"

"CAUSE FACTORS: ... INADEQUATE OPERATIONAL PROCEDURE; CURRENT OUT OF CONTROL FLIGHT PROCEDURES DO NOT MINIMIZE ALTITUDE LOSS IN LOW ENERGY DEPARTURES."

"THE PILOT DIAGNOSED THE SITUATION AS A POSITIVE AOA FALLING LEAF AND APPLIED FULL FWD STICK. THE AIRCRAFT OSCILLATIONS MOMENTARILY STOPPED AND THE NOSE PITCHED DOWN TO 28 DEG NOSE DOWN, AT WHICH POINT THE OSCILLATIONS RESUMED."

Figure 14. Mishap and Hazard Report Excerpts Regarding Recovery Controls
Source: "U.S. Naval Safety Center F/A-18 Out of Control Flight Incident Summary, 1 Jan 1980 to 26 Sep 01," U.S. Naval Safety Center, Norfolk, VA, 26 September 2001.

In 1995, Jaramillo and Ralston conducted non-linear simulations of falling leaf motion in an attempt to recommend suppression strategies. They concluded that falling leaf motion could be simulated with sufficient accuracy to suggest several sophisticated damping techniques to effect recovery.[28] Implementation of their findings would have required expensive and time-consuming flight control law changes. The suggested complex damping techniques could not be applied to a new falling leaf recovery procedure.

In 1996, Foster investigated the flight mechanics of the falling leaf mode in order to develop criteria for predicting susceptibility to this motion so as to avoid this mode in future aircraft designs. Subsequent work by Foster and the NASA team also attempted to determine the primary mechanism for falling leaf recovery. Foster concluded that recovery could not be achieved until the nose-up inertia coupling is reduced or overcome by nose-down aerodynamic control power. Results of several simulations also suggested an alternate recovery technique using full aft stick. This technique appeared to allow the flight control law pitch damping function to reduce the pitch rate activity that in turn reduced the roll inertia coupling.[29]

Alternate Recovery Controls Simulation Study

In January 2000, a renewed interest in analyzing the falling leaf mode was spawned from recent OOCF mishaps. Engineers and test pilots from the NAWCAD conducted several piloted simulations in an attempt to determine the effectiveness of alternate falling leaf recovery procedures, specifically the application of full aft stick.

The procedure identified in figure 15 was used to generate falling leaf motion and was obtained from the F/A-18E/F engineering and manufacturing development program. All simulation events supplied 123 data parameters for analysis.

The time history presented in figure 16 depicts a manned flight simulator event (Run 2 / 2 Feb 2000) that exhibited the characteristics of both the FFS and FAS recovery inputs in one run. Classic falling leaf motion, as defined by in-phase roll and yaw rates, developed 40 – 50 seconds into the run. During this time, the flight control computers were executing the normal control augmentation system (CAS) flight control laws (Spin Switch – NORM). Full forward stick was applied 57 seconds into the run. This action increased the roll rate by approximately 40% and the yaw rate by 30 % in just 8 seconds. Full forward stick was held for 36 seconds with no indication of recovery. At this point, full aft stick was applied. Within 15 seconds, the roll and yaw rates were reduced to zero. These results clearly suggest that a full aft stick procedure may improve recovery characteristics, specifically time to recover and altitude loss, from a confirmed upright (positive AOA) falling leaf.

- Establish 20° - 30° nose high pitch attitude at 200 KCAS
- Select Throttles - Idle
- Program aft stick to decelerate/maintain nose high attitude
- Select Manual Spin Recovery Mode (MSRM) passing 150 KCAS [SPIN Switch – RCVY]
- Cycle full lateral stick passing 120 KCAS after verification that spin mode has engaged
- Controls – Release
- Observe departed motion for ~ 10 seconds or when Falling Leaf motion is verified
- Select Normal flight control mode [SPIN Switch – NORM]
- Observe several cycles of Falling Leaf motion
- Apply recovery controls (FFS or FAS)

Figure 15. Manned Flight Simulator Procedure for Entering a Falling Leaf

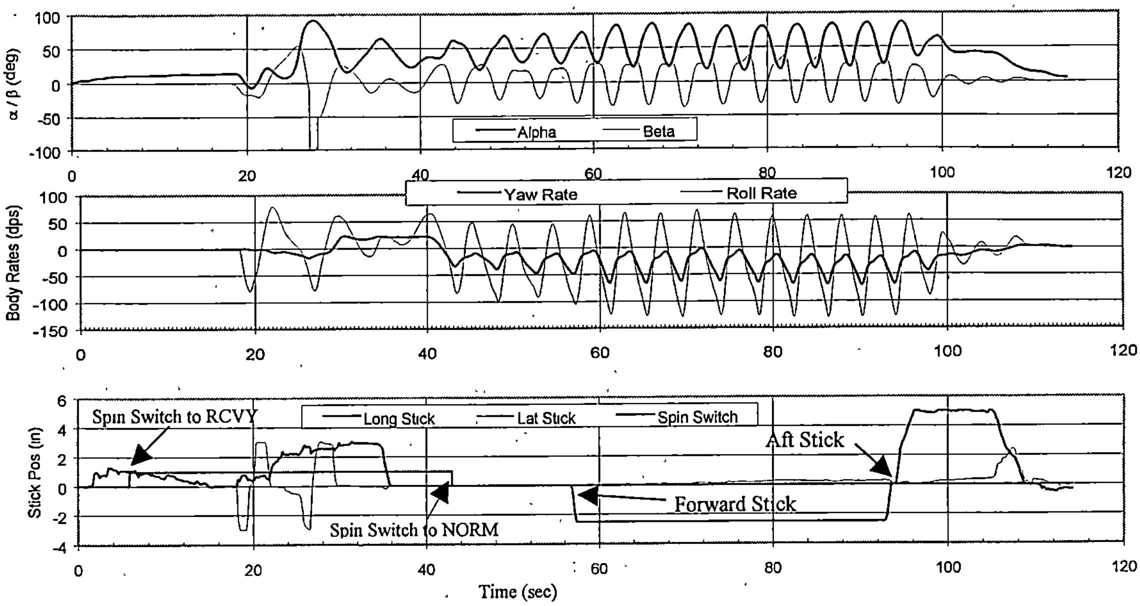


Figure 16. Manned Flight Simulator Data – Run 2, 2 February 2000

Falling Leaf Recovery Controls Flight Test Program

Based on recent mishaps, previous falling leaf research, and the full aft stick recovery controls simulation study, PMA 265 provided funding in March 2000 to conduct a limited flight test program. The purpose of the program was to compare alternate procedures, specifically the application of full aft stick, to the full forward stick procedures for their effectiveness in recovering aircraft from falling leaf motion. Data was collected to determine if the positive results of the recent research and FAS simulations could be reproduced in the flight test environment and to determine the positive or negative effects of the recovery control inputs.

The flight test program consisted of five flights totaling 6.6 flight hours. The test aircraft was an F/A-18B model. The external configuration consisted of clean wing and fuselage stations with a centerline fuel tank. All tests flights were monitored real time from the NAWCAD telemetry ground station. A safety chase aircraft was utilized during each test sortie. A specific NAVAIR flight clearance was issued to permit intentional departures from controlled flight as long as the center of gravity was forward of 23.5% mean aerodynamic chord. Three methods were employed to generate falling leaf motion including tailslides, 100 KCAS vertical recoveries, and Manual Spin Recovery Mode (MSRM) entries.

The 100 KCAS vertical recovery and tailslide maneuvers were initiated at 300 KCAS and 30,000 ft pressure altitude. Peak altitude ranged from 37,000 – 40,000 ft during these maneuvers. Tailslides were executed by establishing a 70° - 90° nose high pitch attitude and releasing the controls once the airplane stopped responding to control inputs. The 100 KCAS vertical recoveries were performed by initiating a vertical climb, and then upon reaching 100 KCAS, applying either a full forward or full aft stick input in an attempt to recover. Flight manual procedures were followed (releasing controls) upon departure. For both tailslides and 100 KCAS vertical recoveries, two to three nose swings of in-phase roll/yaw motion was allowed to develop with controls released before applying the recovery control input (Full Aft Stick or Full Forward Stick).

The manual spin recovery mode entry technique employed during these tests was used extensively during the F/A-18E/F high AOA test program. The MSRM entry procedure consisted of selecting the SPIN switch to RCVY (Recovery) at 40,000 ft pressure altitude and 145 KCAS, lowering the nose to 20° below the horizon, then smoothly pulling to full aft stick. After the pitch rates subsided, small lateral stick inputs (1-2 inches) were used to generate in-phase roll/yaw motion while holding full aft stick. After observing sufficient motion, the SPIN switch was set to NORM (Normal). Recovery controls were then applied with the CAS flight control laws engaged.

Flight Test Results

Overall, fifty test points were executed including sixteen tailslides, twenty-six 100 KCAS vertical recoveries, and eight MSRM entries. Aft stick was applied during six of the fifty test points to recover from falling leaf motion. In each case, recovery was indicated within fourteen seconds from the application of full aft stick. Qualitative pilot comments indicate that positive recovery trends were apparent as soon as aft stick was applied.

Data from one of the test points that utilized FAS to recover from falling leaf motion is presented in figure 17. The pilot utilized the tailslide technique to cause a departure at 33 seconds into the time history. Typical falling leaf motion developed 48 seconds into the run. The pilot applied full forward stick from 51-54 seconds and immediately noted increased body rates. Two seconds later (at 56 seconds), the pilot applied and held full aft stick for nine seconds during which time all body rates ceased. Recovery was indicated four seconds later as the aircraft accelerated through 180 KCAS. These trends were very similar to the piloted simulation results that are presented in figure 16.

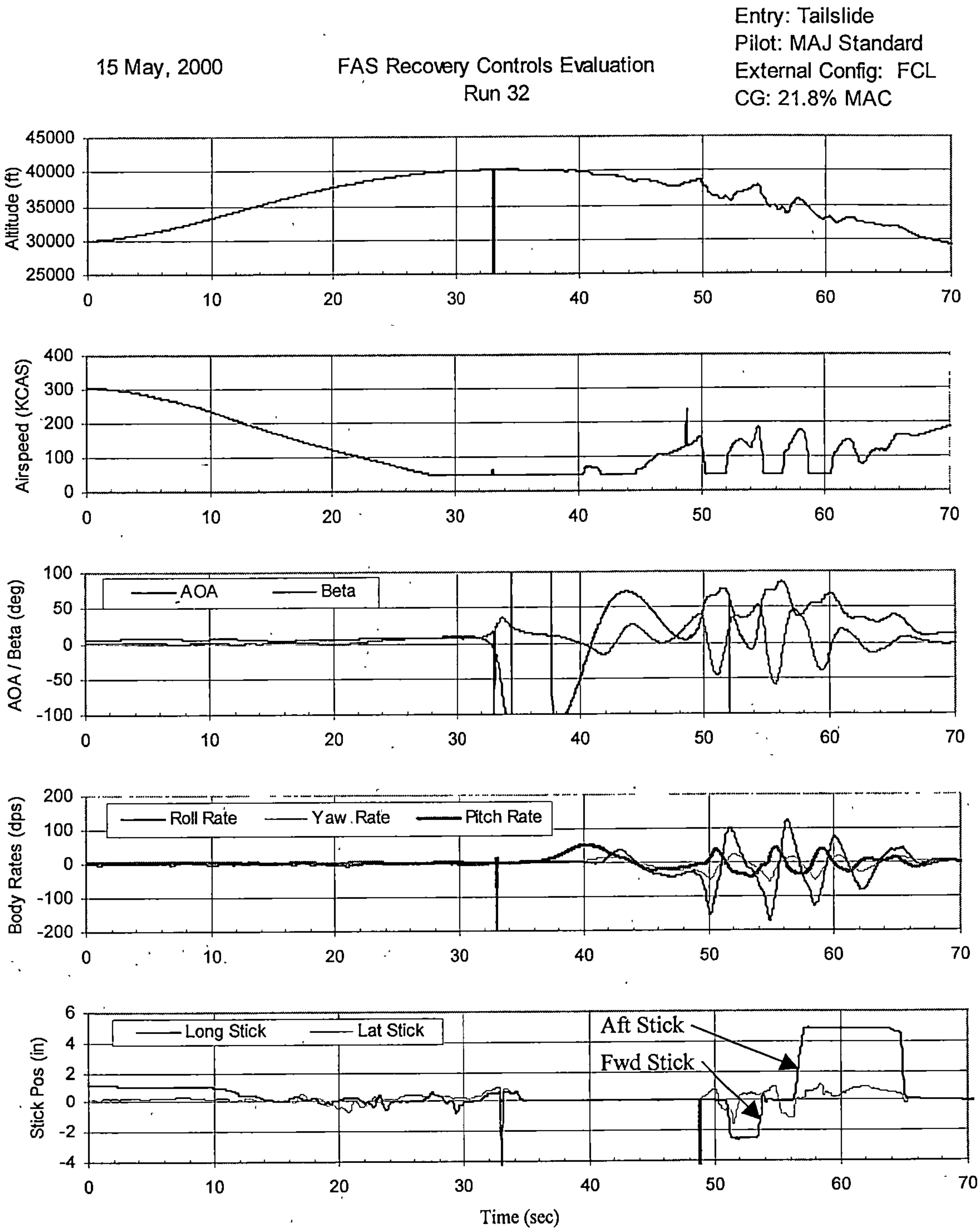


Figure 17. Flight Test Data Showing Full Aft Stick Recovery

The MSRM technique was successful in generating the in-phase roll/yaw motion, however, the motion did not exhibit the light in the seat with sideforce cues common to falling leaf motion and the aircraft recovered immediately with controls released. During two MSRM entry attempts, full aft stick was maintained while selecting the SPIN switch to NORM. The oscillatory motion continued with no sign of damping while holding full aft stick. Releasing the controls produced a rapid recovery (within seven seconds) from this type of motion.

Six test points were executed using a full forward stick input. In each case, FFS produced adverse characteristics that resulted in re-departure. Forward stick inputs increased the rate at which the AOA transitioned from positive to negative and contributed to re-departure due to the resulting low AOA and high sideslip condition. Recovery using FFS may have been possible, however, the precise timing to release the full forward control input was very difficult for the test pilot to determine. When AOA transitioned from positive to negative, the resulting motion was disorienting to the pilots due to the negative g conditions.

Forty-three of the fifty departures recovered with the control stick released. The test method for this evaluation was to allow in-phase roll/yaw to develop with controls released before applying either a full forward or full aft recovery control input. In most cases, the airplane recovered during the controls released phase before the test input could be made. While this result prevented the gathering of FAS recovery data, it did support the effectiveness of releasing the controls as a recovery technique. This recovery technique was very easy to execute and produced reliable recoveries throughout the test program. On average, altitude loss from post-departure gyrations was 5,200 ft, however, several runs required up to 8,500 ft. Altitude loss was determined by subtracting the altitude when recovery was initiated (Accelerating through 180 KCAS and no sideforces or AOA/yaw rate tones) from the altitude at departure (peak of tailslide/vertical recovery)

Data Analysis

The full aft stick recovery controls flight test program investigated alternate falling leaf recovery techniques based on the positive results from engineering simulation. Data from the flight test program was analyzed and suggested that full aft stick was a viable method for recovery and may significantly reduce altitude loss. Since combat maneuvering that could lead to a departure usually occurs at medium to low altitudes (10,000ft-25000 ft) and recovery using current procedures requires up to 12,000 feet, an alternate procedure or a flight control law update is required to reduce the chances of mishap.

Falling leaf motion is extremely complex and no definitive explanation yet exists for how aircraft recover from this state. Several theories have been suggested. Most researchers agree that in-phase roll/yaw motion produces a significant nose up moment due to inertia coupling. This moment is so powerful that it overcomes the nose down moment created by the aerodynamic forces acting on the flight control surfaces.

This theory states that recovery can only be achieved when sufficient airspeed is present to allow the aerodynamic moments to overcome the inertia coupling effects.[30, 31]

Three recovery techniques using longitudinal control inputs were analyzed for their ability to effect falling leaf motion. Applying full forward stick appeared to increase the magnitude of the AOA oscillations and the falling leaf motion. The pitch rate damping feature of the control laws did not work in this case because the system was saturated from both a nose down command from AOA feedback (when AOA > 22°) and from the stick command. Releasing the control stick allowed the flight control computer to command the control surfaces as required to effectively damp the roll, pitch, and yaw rates, however, the stabilator tended to remain at the nose-down stop (+10.5°) whenever AOA was above 22° unless a large pitch rate caused it to come off the stop. Applying full aft stick caused the stabilator to move to the full nose-up stop (-24°). In this case, the flight control system was not saturated and the pitch rate damping feature was allowed to work.

Heller significantly expanded falling leaf research by breaking down the complex motion into individual aerodynamic and inertial components in an attempt to determine a potential recovery mechanism. He based his research primarily on the full aft stick flight test data. He showed that the large AOA oscillations present in falling leaf motion couple into and increase sideslip oscillations thereby causing the motion to be more severe.[32]

Heller further surmised that if the AOA and sideslip oscillations can be damped and controlled, quick recovery from falling leaf motion can be obtained. The application of aft stick gradually arrests the AOA oscillations during each downward swing by apparently increasing dihedral effect (roll due to sideslip). Wind tunnel data seems to support this conclusion, however, Heller recommended studying and collecting additional wind tunnel data to determine exactly how the stabilator affects the roll axis.

Summary

The full aft stick recovery controls test team concluded that releasing the controls provided very dependable departure recoveries. Full forward stick inputs aggravated the initial departure motion and the rapid nose down pitch to negative AOA caused subsequent re-departures and motion that was disorienting to the pilots. Qualitative pilot comments indicated that full aft stick may provide a more rapid recovery from falling leaf motion, however, the insufficient quantity of data combined with the exceptional difficulty of generating sustained falling leaf motion require additional analysis and flight test to reach a final conclusion. The team recommended that the FFS falling leaf procedures be eliminated from the flight manual and replaced with releasing the controls to recover from falling leaf motion. These conclusions were based on the results of previous flight tests, the departure demonstration program, and the simulator research results. Because of the promising nature of the FAS flight tests, the team recommended additional flight tests to investigate the potential benefits of applying FAS to reduce altitude loss.

CHAPTER VI

MEASURES OF EFFECTIVENESS

Several quantitative and qualitative measures of effectiveness (MOE) prove the initial success of the departure training program and the revised OOCF recovery procedures. The quantitative measures are based on the data from the Naval Safety Center and the flight test programs, while pilot and instructor feedback determine the qualitative measures. Analysis of both the quantitative and qualitative measures is particularly important given the relatively short amount of time that the training program and improved procedures have been in place. The quantitative data may have less significance at this early stage, so the qualitative data takes on even greater importance in determining the potential benefits of the program and procedures.

The primary quantitative MOE is the actual number of mishaps since the implementation of the training program and the revised procedures. Zero mishaps have occurred since NAVAIR introduced the departure training program in March 2001 and a single mishap occurred immediately following the release of the revised OOCF recovery procedures in early July 2000. The MOE data from this particular mishap should be disregarded because the low speed, nose high departure occurred only a few thousand feet above the prescribed ejection altitude of 6,000 feet. Under normal circumstances, recovery using the new procedures may require up to 12,000 feet. It could be argued that no recovery procedure could have saved this aircraft, however, if the pilot had received proper training, he may have been able to recognize the situation and apply proper controls to prevent the departure.

A second quantitative MOE is the actual number of reported OOCF incidents. This measure primarily indicates the effectiveness of the revised procedures because only a small percentage of pilots have received the departure training as of September 2001. Only one hazard report has been submitted since the revised procedures were distributed. The report's author, a pilot who had not yet received departure training, indicated that the new procedures were effective in recovering his aircraft from an unintentional departure at 18,000 feet and subsequent falling leaf motion. Data from this incident shows that the pilot released controls within two seconds of the initial indication of departure and recovery was accomplished at 11,500 feet. The fact that only one hazard report has been submitted indicates the initial success and the potential benefits from the revised procedures and departure training program. One must realize, however, that other OOCF incidents, showing flaws with the new procedures or training program, may go unreported.

Another quantitative MOE specific to the improved recovery procedures is provided by the extensive database of intentional departures recorded during the various flight test programs and the departure demonstration flights flown between 1994-2000. Over 2000 departures occurred during that timeframe using a controls released recovery technique and each aircraft recovered above 20,000 feet pressure altitude. The statistics showed that up to 12,000 feet was required to recover using this technique. Also, the database indicated that the aircraft engines and systems remained robust during each departure and subsequent recovery.

Qualitative MOE were obtained from both informal and formal interviews with student pilots, instructor pilots under training, standardization instructors, and program managers. The data gathered from these interviews included general opinions, descriptions of experiences, and suggestions for improvement.

Following the initial certification of six instructor pilots undergoing training in March 2001, a group debrief was conducted to gather comments and impressions about the training program. All participants agreed that the program was worthwhile and was definitely "orders of magnitude" better than the current departure training that students received. The three-phased approach to the training (classroom instruction, simulation, flight training) was applauded with the in-flight, hands-on aspect of the program receiving the most positive comments. Several of the experienced instructors mentioned that personal confidence in their piloting ability was increased after the flight training sorties.

The instructors also brought forward a concern about the training program related to student flight experience. Students were to receive the flight training after approximately 40 hours of F/A-18 flight time. The concern was that with such limited experience, the student might not be able to execute critical cockpit procedures in the event of an aircraft emergency during disorienting OOCF conditions. For instance, in the extremely rare case of an engine surge/stall, only the front seat pilot (generally the student pilot) can shut down an engine. The pilot in the rear seat (generally the instructor pilot) has no ability to execute or complete the required procedures. As a result of these discussions, it was decided that the students would fly from the rear seat until they acquired additional experience with the training program.

The training methods and materials received positive comments from the instructors and the program managers. The required classroom briefings on high angle of attack flying qualities and aircraft preparation were described as informative, clear, and presented at the proper technical level. The fifty-minute training video was considered professional and was praised for keeping the audience's attention. The instructors and program manager appreciated having all of the training resources consolidated in an organized notebook.

Student pilots overwhelmingly reported satisfaction with the training. Prior to the training flight, one student was apprehensive about intentionally forcing the Hornet into an out-of-control situation for training purposes. After the training, however, the pilot commented on how *experiencing* the various cockpit cues prior to departure and *feeling* the sideforce cues to determine the proper OOCF mode were invaluable. The training flight not only gave him confidence in his ability to handle an OOCF situation, it also gave him confidence in the aircraft flight control system's ability to recover from a departure. He concluded by stating that the training prepared him well for his upcoming operational tour and helped him to better judge the physical limits of the aircraft.

Program demand is another significant measure indicating program effectiveness. In addition to several operational fleet squadrons that have requested the training now that it is available, the air forces of several foreign countries that employ the F/A-18 weapon system have also asked for training. The Finnish and Swiss Air Forces obtained training and the Malaysian and Spanish Air Forces received a demonstration flight. The Spanish Air Force has requested additional training for their instructor pilots. Demand for the training program appears to be strong as word spreads about the potential benefits and quality of the program.

Additional qualitative supporting data was obtained from comments and recommendations listed in the mishap reports prior to the adoption of the training program and new recovery procedures. All of the mishap reports written between 1993 and September 2001 recommended that the Navy improve departure training to provide pilots with information on departure characteristics and recovery procedures. Senior Navy leadership also commented on the need for a training program in response to the Hornet OOCF mishap rate. In July 1999, the Chief of Naval Operations reported, "A comprehensive mix of operational risk management training, classroom instruction, and in-flight departure demonstration still remains the most effective approach to minimizing the potential risks associated with Hornet OOCF."[33]

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Since the introduction of the F/A-18 into the US Navy's fleet in 1983, out-of-control flight has been responsible for eleven lost aircraft. According to Naval Safety Center data, the only common element among these mishaps was the training received by the pilots. Therefore, to mitigate crashes due to sustained OOCF modes, a new pilot training program was developed and new recovery procedures were implemented.

The Full Aft Stick Recovery Controls flight test program began evaluating alternative recovery procedures for the most common OOCF mode, *falling leaf* in 2000. This program resulted in improved OOCF recovery procedures for the fleet and suggested a technique that has the potential to substantially reduce altitude loss. One year later, the NAVAIR Departure Training Program was formally introduced to provide academic lectures, a simulation session, and in-flight OOCF training to F/A-18 fleet pilots.

Both quantitative and qualitative measures of effectiveness exist for the new program and procedures. Zero mishaps have occurred since NAVAIR introduced the departure training program and only a single mishap has occurred since the release of the revised OOCF recovery procedures. Also, the only hazard report that has been filed since the revised procedures were distributed indicated that the new procedures were effective. Finally, informal and formal interviews with student pilots, instructor pilots under training, standardization instructors, and program managers indicate that the program was worthwhile, that the methods and materials are of high quality, and the program is in high demand.

Minimizing the number of F/A-18 strike fighter aircraft lost to OOCF is vital to the US Navy for many reasons, including the aircraft's importance to national security, its high cost, and the human value of those trained to operate it. Given these reasons, the initial success of the departure training program and the improved recovery procedures suggests long-term benefits for the US Navy.

Recommendations

In order for the benefits to be fully realized, the following recommendations for the departure training program and the OOCF recovery procedures are suggested.

Departure Training Program

The implementation of the departure training program should be accelerated. As of September 2001, only one of the three F/A-18 training squadrons has been qualified and has begun training students. The excessive workload and the significant student backlog have prevented the remaining squadron instructors from scheduling their training. Because Navy leadership has invested substantial resources for program development and has revised the F/A-18 training curriculum to incorporate the departure training flight, it is recommended that time and resources be made available to accomplish this essential training.

More NAVAIR standardization pilots should be trained. Employing more standardization pilots will enable the training of FRS instructor pilots and will provide additional resources for training operational squadrons as well as foreign military customers.

Each student, following the training, should complete a brief feedback form. Data and comments would be solicited and addressed in an effort to constantly improve the program.

Out-of-Control Flight Recovery Procedures

A two-phase approach with respect to the OOCF recovery procedures should be implemented. In the short term, update the aerodynamic databases of engineering simulators with static and dynamic stability coefficients obtained from wind tunnel data so that a repeatable falling leaf entry technique can be established. Once this is complete, a second flight test program to evaluate full aft stick recovery procedures should be conducted. The existing flight test data has been analyzed and it showed significant potential for reducing the time and altitude necessary for recovery.

In the long term, using the detailed analysis of the available falling leaf data, flight control laws to assist with the damping of the falling leaf motion should be designed. This process will take significant time and financial resources due to the extensive flight test program required to ensure success.

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APPENDIX

APPENDIX A

AIRCRAFT DESCRIPTION

APPENDIX A

AIRCRAFT DESCRIPTION

Airframe Description

The F/A-18 was a high performance, twin engine, supersonic fighter and attack airplane manufactured by McDonnell Douglas Corporation (now Boeing, St. Louis). The airplane was characterized by moderately swept variable camber mid-mounted wings, twin vertical stabilizers mounted forward of the horizontal stabilators and canted outboard 20°, and wing leading edge extensions (LEX) mounted on each side of the fuselage from the wing roots to just forward of the windshield. The airplane was configured with full span leading edge flaps, inboard trailing edge flaps, and outboard ailerons on each wing. The flight control system consisted of two digital flight control computers that utilized a full authority control augmentation system to operate the hydraulically driven control surfaces. The aircraft was powered by two General Electric F404-GE-400 or -402 augmented turbofan engines each rated in excess of 16,000 pounds maximum uninstalled static sea level thrust.

The baseline F/A-18 design incorporated a highly swept leading edge extension to generate a strong vortex flow pattern at medium to high angles of attack. The strong vortex served to energize the wing boundary layer and aid in the reattachment of the flow along the inner wing root at high angles of attack. The nose or forebody of the aircraft was generally circular in cross section which transitioned to an ellipse with a vertical major axis. This shape also produced vortex flow and in certain cases combines with the LEX vortex to create substantial vortex lift.

Flight Control System Description

The primary flight control system relied on four digital computers working in parallel to accept pilot commands and data from aircraft sensors, process control law software, and distribute signals to the flight control surfaces. This closed loop, fly-by-wire control augmentation system employed gain scheduling and cross-axis interconnects to achieve the best possible flying qualities throughout the flight envelope and to enhance the stability characteristics of the natural airframe. Numerous signal filters were imbedded into the control law software to actively control unwanted oscillations due to airframe structural modes. The quadruplex system was designed to provide "two fail operate" primary control capability. Backup electrical and mechanical open loop control modes were provided in case of multiple flight control computer or input sensor failures.

Two flight control computers (FCC), each consisting of two signal processing channels, housed the software and memory required to process the flight control laws. The control laws utilized transfer functions between the input sensor signals (pilot commands and aircraft sensors) and the output flight control surface actuator commands. The control laws determined proper control surface deflections based on feedback from the aircraft motion sensors. Control law gains were scheduled according to sensed airspeed and angle of attack. A set of fixed gain schedules were provided to the pilot via the GAIN OVERRIDE cockpit switch in the event of a pitot-static system or motion sensor system failure.

The aircraft motion sensors consisted of two Rate Sensor Assemblies (RSA) and two Accelerometer Sensor Assemblies (ASA). Each RSA contained six gyroscopes to measure aircraft pitch, roll, and yaw rates. Each ASA contained four linear accelerometers to measure aircraft normal and lateral acceleration. Electrical signals proportional to the body rates and accelerations were fed back to each channel of the FCC for processing.

The pitot-static system sensed raw flight and atmospheric conditions using two L-shaped probes. The probes were mounted symmetrically on the lower portion of the forward fuselage. Each probe was plumbed for two static pressure ports and one pitot (dynamic) pressure port. Pneumatic lines were connected from each L-probe to the Air Data Sensor (ADS). The ADS contained an absolute pressure transducer to quantify static pressure and a differential transducer to measure compressible dynamic pressure, Qc. Electrical signals, proportional to the measured pressures and corrected for position source errors, were sent to each FCC channel. The air data sensor output was used for all control law gain scheduling.

The angle of attack system sensed the alignment of the local air stream during flight by means of two conically shaped probes. The probes were mounted symmetrically on the sides of the forward fuselage and were designed to measure local angles of attack from –14° to 56°. Each probe was mechanically connected to redundant rotary position sensors. Electrical signals, proportional to the angle between the probe position and a fuselage reference line, were averaged to determine the local angle of attack. The average local angle of attack was then corrected for fuselage effects based on flight phase and sent to each FCC channel as true AOA.

The pilot controlled the aircraft using a center configuration control stick and conventional rudder pedals. The maximum stick and rudder pedal displacements are summarized in table 1. Feel springs were provided to each pilot control due to the irreversible nature of the flight control system. Redundant lateral and longitudinal stick position sensors provided signals to the flight control computers. Redundant rudder pedal force sensors provided signals to the flight control computers. The two-seat models could be fitted with a set of pilot controls for the aft cockpit.

Table 1. Maximum Control Stick Displacements

Pilot Control	Maximum Displacement	
Longitudinal Stick Position	5.0 inches aft	2.5 inches forward
Lateral Stick Postion	3.0 inches left	3.0 inches right
Rudder Pedal Position	1.0 inch left	1.0 inch right

The control laws were optimized for each of two flight phases; Auto Flaps Up (AFU) for up and away flight and Powered Approach (PA) for takeoff and landing. The flight phase and hence, control laws, were selected by the pilot using the cockpit Flap switch. The three position switch was set to AUTO for up and away flight and to HALF or FULL for powered approach flight. The flight control system automatically transitioned from PA to AFU if airspeed was greater than 243 KCAS even if the flap switch was not actuated. PA mode could only be selected if airspeed was less than 243 KCAS and the flap switch was in HALF or FULL.

Longitudinal Control Logic

The flight control laws for the longitudinal axis employed an optimized blend of pitch rate, normal acceleration, and angle of attack feedback to produce excellent aircraft stability and controllability. All inner loop gains were scheduled with dynamic pressure, so that the gains were reduced as airspeed increased to avoid excessive control surface hinge moments. The initial FCC command (forward path) to the actuator was designed to provide uniform pitch acceleration. The aircraft response, based on feedback signals from the pitch gyro and the normal accelerometer, was compared to the pilot command (longitudinal stick position). The resulting error or difference between command and response was reduced to zero by command signals back to the actuator (forward path). Angle of attach feedback was incorporated above 22° AOA to increase the stick force cues to the pilot as airspeed decreased. Data from the roll and yaw gyros were also fed back to the longitudinal control laws to reduce the effects of pitch inertial coupling (product of roll and yaw rates).

Lateral Control Logic

The flight control laws for the lateral axis employed roll rate feedback to augment the aircraft's natural roll damping characteristics. The pilot's lateral stick position command was added to the roll rate feedback signal to control the ailerons, the differential stabilator, and differential leading and trailing edge flaps. Each roll control surface gain was scheduled with dynamic pressure and/or angle of attack. For instance, aileron and differential stabilator gain was scheduled with AOA and air data feedback to eliminate undesirable adverse yaw during rolling maneuvers at low speed/high angles of attack. The gains were also reduced as airspeed increased to avoid excessive control surface hinge moments. The gains were also modified as external stores are added to the hard points on the wings.

Directional Control Logic

The flight control laws for the directional axis employed an optimized blend of yaw rate and lateral acceleration to augment the aircraft's directional stability and directional damping characteristics. The yaw rate that was fed back to the FCC was actually a combination of the body axis roll and yaw rates ($r\cos\alpha - p\sin\alpha$) that yield the stability axis yaw rate. The yaw rate component ($r\cos\alpha$) provided Dutch roll damping and the roll rate component ($p\sin\alpha$) served to reduce sideslip at high angles of attack. A cross-axis rolling surface to rudder interconnect (RSRI) was incorporated to minimize sideslip and hence automatically coordinate turns. A rudder pedal to rolling surface interconnect provided the pilot with the capability to use the rudder pedals to roll the aircraft. Lateral acceleration feedback was incorporated to assist with minimizing sideslip during turn coordination. All inner loop gains were scheduled with dynamic pressure, so that the gains were reduced as airspeed increased to avoid excessive control surface hinge moments. The gains were also limited in portions of the envelope to improve departure resistance with full pedal inputs.

Spin Recovery Mode Logic

The F/A-18 flight controls laws provided special logic to detect a spin condition. When spin conditions were met, the flight control law feedbacks were removed and the pilot was given full authority of all control surfaces (rudder, aileron, and stabilator) to effect recovery. The system provided an automatic and manual mode.

The automatic spin recovery mode (ASRM) was engaged when the following conditions were met:

- Yaw rate (filtered with a 7.2 sec lag) exceeded 15 degrees per second
- Airspeed was less than 121 KCAS
- Anti-spin lateral stick inputs were applied

Once the system detected a spin condition, the cockpit digital display indicators (DDI) depicted the spin recovery mode format that included an anti-spin command arrow (see figure 9). Applying lateral stick in the direction of the command arrow gave the pilot full authority of the control surfaces (feedbacks removed). If the pilot inadvertently applied lateral stick in a direction opposite to the command arrow, the normal control laws (with feedback) were executed which may have aggravated the spin condition. The ASRM disengaged when the product of yaw rate and filtered yaw rate decreased below 225 deg^2/sec^2. This was to prevent over control and a subsequent spin in the opposite direction.

The manual spin recovery mode (MSRM) was engaged when the following conditions were met:

- Cockpit SPIN switch was set to the RCVY (Recovery) position
- Airspeed was less than 121 KCAS

The anti-spin command arrow was displayed if the filtered yaw rate was greater than 15 degrees per second. The MSRM was disengaged automatically if airspeed was greater than 239 KCAS or if the SPIN switch was set to the NORM (normal) position.

APPENDIX B

DEPARTURE TRAINING PROGRAM BRIEFING GUIDES

F/A-18A/B/C/D DEPARTURE TRAINING PROGRAM

SIMULATOR BRIEFING GUIDE

Simulator Time: 1.0 hour

Brief Time: 1.0 hour

Debrief Time: 1.0 hour

Simulator: F/A-18 operational flight trainer, weapons tactics trainer, or piloted engineering simulator

Prerequisites: Personal study and complete review of the following documents and videotape prior to the simulator session:

a. F/A-18A/B/C/D NATOPS (A1-F18AC-NFM-000) - PART I, section 2.8 and PART IV
b. NAWCAD Training Video #806021: The Edge of the Envelope: Understanding the F/A-18 Out of Control
c. NAVAIR Flight Clearance for the Departure Training Program
d. NAVAIR INST 3502, Establishment of the F/A-18A/B/C/D Fleet Departure Training Program

Successful completion of ground training provided by a qualified NAVAIR Departure Training Standardization Pilot or FRS Departure Training Instructor Pilot:

a. F/A-18A/B/C/D High Angle of Attack Flying Qualities and Departure Characteristics Briefing
b. F/A-18A/B/C/D Flight Control Surface Rigging Brief
c. F/A-18A/B/C/D Radome Brief

Mission: To expose students to the specific training maneuvers and cockpit procedures required for the flight-training phase. To discuss and review departure recognition cues and recovery procedures. To practice the departure maneuvers to be instructed in the F/A-18 aircraft and expose the student to lessons learned from previous departure training evolutions.

STUDENT BRIEF

1. Aircraft G Limitations: Symmetrical and asymmetrical "G" limits will be discussed from memory for 32,500 and 36,000 lb gross weights. (NATOPS)

2. Aircraft AOA Limitations: Discuss from memory AOA limitations for Fighter Escort Configuration with centerline tank and CG from 17-23.5 % MAC. Also discuss F/A-18 B/D AOA limits due to Mach number. (NATOPS)

3. Key Airspeeds, AOAs: State key airspeeds, AOAs and significance of each. (TOPGUN Chap 33)

4. Out of Control Flight: Discuss NATOPS description of the factors that directly affect entry and recovery of aircraft when out of control flight conditions exist. (NATOPS)

5. OCF Modes: Discuss the different OCF modes and their indications. (NATOPS)

6. OCF Procedures: State the immediate actions steps verbatim from memory. (NATOPS)

7. NATOPS Restrictions: State from memory applicable NATOPS prohibited maneuvers. (NATOPS)

8. Engine Relight Procedures: State from memory NATOPS procedure for engine relight. (NATOPS)

9. Engine Parameters: State from memory Hung / Stall / Overtemp engine indications. (NATOPS)

IP BRIEF

1. F/A-18 Departure Flight Clearance: Discuss in detail the flight clearance that authorizes the performance of the NATOPS prohibited maneuvers to be conducted only on this specific flight.

2. F/A-18 Rig Checks: Discuss the PMCF "C" profile flight control surfaces rig checks, and accelerated flight radome checks. Reference date and type of last PMCF flown on assigned aircraft.

3. F/A-18B/D Departure Susceptibility Regions: Brief departure tendencies and techniques for reducing aircraft susceptibility.

4. Low AOA Departure Maneuver: Brief the conduct of the Low AOA Departure maneuver to be demonstrated during this flight.

5. Engine Anomalies: Brief potential engine anomalies that may be experienced during departure demonstration to include the dual fuel starvation relight profile.

SIMULATOR CONDUCT

1. Vertical Recovery: 15,000 ft AGL / 400 kts in MAX power. Perform the maneuver by pulling 4 G's to the vertical, maintain pure vertical until 200 kts then smoothly pull to the horizon not exceeding 35° AOA. Note altitude gain. This is a "tactical" vertical recovery. Emphasize the "tactical" pitch authority available with ≥ 200 kts. Below 200 kts a longitudinal pull may not be the optimum transition from the vertical.

2. High AOA Static Stability Demonstration and Radome Check: 30,000 ft AGL / 250 kts. Wing level, trim lateral and directional to ensure a centered ball. Reduce throttles symmetrically to IDLE. Monitor DDI FCS display. Sample lateral stick and rudder pedals inputs for bank- to- bank rolls at 15 ° and 25 ° AOA. Smoothly increase longitudinal stick full aft, observe flight characteristics. Recover - neutralizing longitudinal stick and advance throttles.

3. Accelerated Flight Radome Checks: 35,000ft MSL / 200 kts. Reduce throttles to idle, roll into a left/right 90° AOB turn, then apply full aft stick. Hold for two seconds (observe roll, yaw and pitch rate). Repeat in opposite direction.

4. Vertical Departure: 28,000 ft AGL / 300 kts in MIL power. Perform the maneuver by pulling 2-3 G's to the vertical, maintain pure vertical until 100 kts then smoothly pull to the horizon not exceeding 35 deg AOA. Attempt to keep the aircraft's nose tracking across the horizon. When tracking of aircraft's nose across the horizon is no longer possible, reduce throttles to idle. Recover per NATOPS OCF procedures.

5. Automatic SRM Demonstration: 35,000 ft MSL (minimum 30,000 ft AGL) / 150 kts. Slowly reduce both throttles to IDLE. Maintain altitude with back-stick. At AOA tone onset, increase one engine smoothly to MIL, while smoothly applying full aft stick (maintain stick against aft stop throughout the maneuver with no more than 1 inch of right lateral stick). Identify / observe spin motion. Check DDI - Spin Mode, (Note: Spin arrow appearance and direction). Slowly apply lateral stick with Spin Arrow.

Check DDI – Spin Mode Engaged. Observe yaw rate - Stop. Check both throttles – IDLE. Complete NATOPS recovery.

6. <u>Low AOA / Rudder Departure Demo</u>: IP will demonstrate this maneuver during the flight phase. 35,000 – 30,000 ft AGL / < 210 kts with centerline in MIL power (adjust throttle friction for stiff throttles). Pull aircraft up to 25° pitch attitude. Pushover to 0 ° (± 5 °) AOA, then abruptly apply full rudder pedal and hold. Maintain 0 ° to 3 ° AOA (± 5 ° limit) with longitudinal stick. Retard throttles to IDLE upon first sign of departure (vortex rumble, side forces, etc.). Upon departure, recover per NATOPS OCF procedures.

7. Repeat maneuvers as required.

F/A-18 B/D DEPARTURE TRAINING PROGRAM
FLIGHT BRIEFING GUIDE (4 June 01)

Mission Time: 1.2 hours (per flight)

Brief Time: 2.0 hours

Debrief Time: 2.0 hours

Aircraft Config F/A-18B/D, Sta 1, 2, 4, 6, 8, 9 – empty
Sta 3, 7 – empty or pylon
Sta 5 - EFT

Weather: Day / 15,000 / 3nm (A defined horizon, ground reference, and maximum cloud coverage of 6000 ft AGL Ovc and/or 15,000 ft Bkn is required for all departure training flights)

Prerequisites: Successful completion of ground training and simulator session provided by a qualified NAVAIR Departure Training Standardization Pilot or FRS Departure Training Instructor Pilot

Mission: To expose student pilots to the advanced handling characteristics of the F/A-18 through flight demonstration of impending departure cues, aircraft departure characteristics, and recovery procedures. Provide the standardization flights required to qualify the designated NAVAIR standardization pilots and FRS instructors for departure maneuver instruction.

Flight Execution:

a. All maneuvers will be terminated at or above 25,000 ft or with the appearance of any Caution/Advisory

b. One flight for FRS students or fleet pilots authorized for Departure Training

c. Three flight IUT syllabus – flight #1and #2 IUT in front seat, flight # 3 IUT back seat (Check Flight).

STUDENT BRIEF

1. Aircraft G Limitations: Symmetrical and asymmetrical “G” limits will be discussed from memory for 32,500 and 36,000 lb gross weights. (NATOPS)

2. Aircraft AOA Limitations: Discuss from memory AOA limitations for Fighter Escort Configuration with centerline tank and CG from 17-23.5 % MAC. Also discuss F/A-18 B/D AOA limits due to Mach number. (NATOPS)

3. Key Airspeeds, AOAs: State key airspeeds, AOAs and significance of each. (TOPGUN Chapter 33)

4. Out of Control Flight: Discuss NATOPS description of the factors that directly affect entry and recovery of aircraft when out of control flight conditions exist. (NATOPS)

5. OOCF Modes: Discuss the different OCF modes and their indications. (NATOPS)

6. OOCF / Spin Procedures: State the immediate actions steps verbatim from memory. (NATOPS)

7. NATOPS Restrictions: State from memory applicable NATOPS prohibited maneuvers. (NATOPS)

8. Engine Relight Procedures: State from memory NATOPS procedure for engine relight. (NATOPS)

9. Engine Parameters: State from memory Hung / Stall / Overtemp engine indications. (NATOPS)

IP BRIEF

1. F/A-18 Departure Flight Clearance. Discuss in detail the COMNAVAIRSYSCOM Flight Clearance that authorizes the performance of the NATOPS prohibited maneuvers to be conducted only on this specific departure training flight. Review all limitations imposed by the flight clearance (e.g. Aft CG limit).

2. F/A-18 Rig Checks. Discuss the PMCF "C" profile flight control surfaces rig checks, and accelerated flight radome checks. Reference date and type of last PMCF flown on assigned aircraft.

3. F/A-18B/D Departure Susceptibility Regions. Brief departure tendencies and techniques for reducing aircraft departure susceptibility.

4. Low AOA Departure Maneuver. Brief the conduct of the Low AOA Departure maneuver to be demonstrated during this flight.

5. Engine Anomalies. Brief engine anomalies that may be experienced during departures.

6. Special Precautions. Brief the special precautions for the departure training flight and lessons learned from previous flights.

FLIGHT CONDUCT

1. Airborne Rig Check. **(IUT Only / As Required)** 10,000 ft MSL / 200 kts. Do not trim laterally after setting takeoff trim. Check memory inspect UNIT 14, ADDRESS 5016 first and third lines are all ZEROS. If first and third lines are not zero, adjust lateral trim to zero reading. In wings level, 1 "G " flight, balance ball for trimmed flight. Release stick and record direction and time to 30 deg AOB (should be > 6 sec). Repeat rig check at 300, 400 and 500 kts. Ball may be re-centered at each trim speed before check.

ABORT Criteria: Observed roll rates greater than 5 deg/sec - RTB

2. High AOA Static Stability Demonstration and Radome Check. 35,000 ft AGL / 250 kts. Trim aircraft for level flight to ensure a centered ball with zero roll rate. Reduce throttles to IDLE to initiate deceleration. Monitor DDI FCS display throughout maneuver. Note buffet onset and LEF / TEF motion during the deceleration. Sample lateral stick and rudder pedal inputs at 15 and 25 deg AOA, noting FCS response. Set power as required to minimize altitude loss. Continue decel and observe wing rock at 38-42 deg AOA. Smoothly program forward stick to eliminate wing rock (~30 deg AOA) and then pull smoothly to full aft stick (~2 sec input). Note initial heading. Once full aft stick is obtained, hold for 5 seconds and note yaw rate changes as seen by heading deviations. Recover - Neutralize longitudinal stick and advance throttles.

ABORT Criteria: RTB if any of the following occur:

1. Departure from controlled flight
2. Distinct yaw acceleration with side-force build-up
3. Heading change greater than 60 deg after 5 seconds at FAS
4. Spin Arrows displayed

3. Accelerated Flight Radome Checks. 35,000ft AGL / 200 kts. Reduce throttles to idle, roll into a left/right 90° AOB turn, then smoothly apply full aft stick (~2 second input). Hold aft stick for five seconds and note yaw, rate. Repeat in opposite direction above 30,000 ft AGL.

ABORT Criteria: RTB if any of the following occur:

1. Departure from controlled flight
2. Distinct yaw acceleration with side-force build-up
3. Aircraft tendency to roll upright with roll attitude change greater than 60 deg in 5 seconds
4. Spin Arrows displayed

4. Automatic SRM Demonstration. 35,000 ft AGL / 150 kts. Trim aircraft for level flight to ensure a centered ball with zero roll rate. Slowly reduce both throttles to IDLE and set pitch attitude to approximately 15 deg to initiate deceleration. Smoothly program aft stick as required to maintain nose at horizon.. At AOA tone onset, increase one engine smoothly to MIL. Maintain stick against aft stop throughout the maneuver with no more than 1 inch of opposite lateral stick to the intended spin direction. Identify / observe spin motion. Check DDI - Spin Mode, (Note: Spin arrow appearance and direction). Slowly apply up to full lateral stick with Spin Arrow. Check DDI – Spin Mode Engaged. Observe yaw rate - Stop. Check both throttles – IDLE. Complete NATOPS recovery.

KNOCK IT OFF Criteria: If the spin motion begins to oscillate with noticeable increasing roll and pitch rates – Recover. The spin should be very smooth in a relatively level attitude.

CAUTION: Lateral stick inputs greater than 1 inch opposite to the intended spin direction (pro-spin) will result in excessive yaw rates and will reduce the stall margin of the engines.
With oscillatory spin conditions, the recovery may be dynamic and may result in nose slice departure.

5. Low AOA / Rudder Departure Demo. **(IP will demonstrate this maneuver.)** 35,000 ft AGL / < 210 kts with centerline in MIL power (adjust throttle friction for stiff throttles). Pull aircraft up to 25° pitch attitude. Pushover to 0 ° (± 5 °) AOA, then abruptly apply full rudder pedal and hold. Maintain 0 ° to 3 ° AOA with longitudinal stick. Retard throttles to IDLE upon first sign of departure (vortex rumble, side forces, etc.). Upon departure, recover per NATOPS OCF procedures.

CAUTION: Airframe overstress possible if airspeed > 210 kts during rudder pedal input.

6. Vertical Departures: 30,000 ft AGL / 300 kts in MIL Power. Calculate CG prior to each maneuver.

(1) (Tailslide) MIL Power. Smoothly pull the nose up to attain 70 ° – 90° pitch attitude with the waterline symbol (1% rule). Use longitudinal stick to maintain nose position. Retard throttles to IDLE at departure. Recover per NATOPS procedures.

(2) (100 kt Vertical Recovery) MIL Power. Perform the maneuver by pulling 2-3 G's to the vertical. Maintain pure vertical until 100 kts then smoothly pull to the horizon. Attempt to keep the aircraft's nose tracking through the horizon. When tracking of aircraft's nose is no longer possible, reduce throttles to idle. Recover per NATOPS OCF procedures. Repeat maneuver as required.

KNOCK IT OFF Criteria: If any FCS caution appears while pulling to the vertical gently roll the aircraft to the nearest horizon and pull the nose down to recover.

******** MSRM DEMO FOR STANDARDIZATION PILOTS ONLY********

7. Manual Spin Recovery Mode (MSRM) Demonstration. At 35,000 ft AGL, 200 KCAS, wings level, 1 g flight check that the fuel transfer is normal. The flight clearance authorizes selection of the spin recovery switch below 250 KCAS. Set the Spin Recovery Switch - RCVY. Ensure flight controls remain in CAS. If not return the switch to NORM and terminate check. Verify both DDI's - SPIN MODE. Raise the nose to 25° nose up pitch attitude and reduce power to IDLE. Unload with slight forward stick to keep AOA between 10 and 20° until the SRM engages, at 120 KCAS. Smoothly capture level flight and modulate thrust to maintain level unaccelerated flight at less than 230 KCAS and 20° AOA. Stabilize briefly using small lateral stick deflections and observe the deflection of the ailerons and adverse yaw. Do not exceed 230 KCAS. Perform banked aileron only, rudder only, and coordinated turns using less than 30° of bank angle. Set the Spin Recovery Switch - NORM. No significant altitude loss is expected. (Note: With increasing side force, AOA or yaw tone, set Spin Recovery Switch – NORM)

******** MSRM DEMO FOR STANDARDIZATION PILOTS ONLY********

VITA

Steve Potter received the Bachelor of Science degree in Aerospace Engineering from the University of Colorado in 1989. He worked for six years as an engineer and instructor at the Johnson Space Center in Houston, Texas prior to becoming a flight test engineer at the Naval Air Warfare Center Aircraft Division. He was selected to attend the US Naval Test Pilot School in 1998 and successfully completed the fixed wing-engineering curriculum in June 1999. He entered the Master's program in Aviation Systems at The University of Tennessee in 1999 and received the degree in December 2001.

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