12-2004

Development of F/A-18 Spin Departure Demonstration Procedure with Departure Resistant Flight Control Computer Version 10.7

David J. Park
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by David J. Park entitled "Development of F/A-18 Spin Departure Demonstration Procedure with Departure Resistant Flight Control Computer Version 10.7." 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.

Robert. B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Charles T. N. Paludan, Richard J. Ranaudo

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Anne Mayhew

Vice Chancellor and Dean of
Graduate Studies

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Development of F/A-18 Spin Departure Demonstration Procedure with Departure Resistant Flight Control Computer Version 10.7

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

David J. Park
December 2004

DEDICATION

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

It is further dedicated to my parents, Young Joon Park and Keal Soo Han,
for their continuous support and guidance;
giving me the opportunity for higher education;
and raising me to become a productive member of our society.

ACKNOWLEDGMENTS

I wish to thank all those who helped me complete my Master of Science degree in Aviation Systems. I would like to thank Major Randy "Komrade" Bresnik for passing down the F/A-18 Departure Demonstration Project Officer job to me; Mr. Bob David (Project Engineer) for inviting me to be a part of the Flight Control Computer Operation Flight Program Version 10.7 (v10.7) flight test team; Lt. Aaron "Lurch" Rouland (v10.7 Project Officer) for allowing me to fly most of the spin test flights and educating me on the details of v10.7; Mr. Steven Potter for including me in the Departure Demonstration development team and supporting me with the necessary flight test data; and Ms. Jessica Holmburg for educating me on the technical details of v10.7.

I would also like to thank the entire v10.7 test team, The Boeing Company, Naval Air Warfare Center Aircraft Division, and PMA-265 for the great test program. A debt of gratitude is also owed to the United States Marine Corps and the Department of Navy for approving the necessary funds to complete my Master's Degree.

ABSTRACT

The purpose of this study was to evaluate the capability to demonstrate F/A-18 Hornet departure characteristics, mainly the spin, with Flight Control Computer (FCC) Operation Flight Program (OFP) Version 10.7 (v10.7). Version 10.7 was released to the Navy and Marine Corps F/A-18A/B/C/D fleet in 2003. Version 10.7 was developed based on the existing FCC OFP (v10.5.1) to minimize out-of-control flight or departure related mishaps. Version 10.7 was only a software upgrade and no hardware change to the existing F/A-18 was made. Version 10.7 was remarkable since most of the known F/A-18 departure prone flight envelopes were rendered departure free by software change alone. Although v10.7 eliminated most of the F/A-18 departure prone areas, it did not eliminate F/A-18 departures completely. Therefore, there still exists a need to train pilots in F/A-18 departures and a need for Departure Demonstration Syllabus.

As a result of departure resistant features of the new FCC OFP, significant portion of the F/A-18 Departure Demonstration Syllabus had to be changed. Several test flights were conducted to re-develop the syllabus. These flight test results revealed that existing spin entry procedure would not be sufficient to enter and sustain the spin. Most of the flight tests to re-develop the syllabus were spent on fine tuning the repeatable spin entry procedure and sustaining the spin long enough for instructional purposes.

Recommended procedure proved to be the best repeatable spin entry procedure. This procedure allowed sustained spin for one turn after the pro-spin flight control inputs were removed. This one turn was necessary for pilots to evaluate the spin characteristics of the F/A-18 and train them to use proper procedures to recover from sustained spins.

PREFACE

A large percentage of the data contained in this thesis was obtained during tests conducted by the F/A-18A-D Flight Control Computer Operation Flight Program Version 10.7 Regression Flight Test Program. Additional flight test data were obtained during flight tests conducted to fine-tune the F/A-18B Departure Demonstration procedures. These flight test data were not part of the F/A-18A-D Flight Control Computer Operation Flight Program Version 10.7 Regression Flight Test Program and have not been published. The research, results, conclusions, and recommendations presented are the opinion of the author and are not an official position of the United States Department of Defense, the Office of the Secretary of Defense, the United States Marine Corps, the United States Navy, or the F/A-18 Program Office (PMA-265).

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LIST OF ABBREVIATIONS

AOA	Angle of Attack
AOB	Angle of Bank
ADC	Air Data Computer
APU	Auxiliary Power Unit
ASRM	Automatic Spin Recovery Mode
CAS	Control Augmentation System
Cl_{max}	Angle of Attack for the Highest Lift Available
DDI	Digital Display Indicator
FAS	Full Aft Stick
FCC	Flight Control Computer
FCS	Flight Control System
FMS	Foreign Military Sales
FRS	Fleet Replacement Squadron
HUD	Heads-Up-Display
INS	Inertial Navigation System
IP	Instructor Pilot
KCAS	Knots Calibrated Airspeed
LEX	Leading Edge Extensions
MAX	Maximum Afterburner
MSRM	Manual Spin Recovery Mode
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command
NAWCAD	Naval Air Warfare Center Aircraft Division
OCF	Out-of-Control Flight
OFP	Operation Flight Program
psf	Pounds per Square Foot
Qc	Dynamic Pressure
RP	Replacement Pilot
SA	Situational Awareness
TAS	True Airspeed
USNTPS	United States Naval Test Pilot School
VX-23	Air Test and Evaluation Squadron Two Three

CHAPTER I
INTRODUCTION

The combat-proven F/A-18 Hornet is a single- and dual-seat, twin-engine multi-mission tactical aircraft. It is the first tactical aircraft designed from its inception to carry out both air-to-air and air-to-ground missions. The original F/A-18A (single-seat) and F/A-18B (tandem two-seat) became operational in 1983 replacing United States Marine Corps and Navy F-4s and A-7s. The F/A-18 has a digital control-by-wire flight control system, which provides excellent handling qualities, and allows pilots to learn to fly the airplane with relative ease. At the same time, this system provides exceptional maneuverability and allows the pilot to concentrate on operating the weapons system. Today, the F/A-18 is in service with the United States Marine Corps and Navy, the air forces of Canada, Australia, Spain, Kuwait, Finland, Switzerland, and Malaysia. As of December 2002 Hornet pilots have accumulated more than five million flight hours. There are currently 1,290 Hornets flying in 58 active duty, reserve and test squadrons for the United States Marine Corps and Navy. A brief description of the F/A-18 Hornet is given in Appendix A and a picture is shown in Figure A-1. "F/A-18" or "Hornet" will be used throughout this thesis in reference to F/A-18A/B/C/D while any reference to the Super Hornet will use "F/A-18E/F."

Since the introduction of the F/A-18 Hornet, more than twenty have been lost to out-of-control flight (OCF), particularly a mode known as "falling leaf."[1] This mode is typically entered following slow speed, nose-high maneuvering. The aircraft may then lose or "depart" control – rapidly oscillating from side to side like a falling leaf. As a result, there has been a growing concern that fleet F/A-18 pilots do not have a thorough understanding of F/A-18 high angle of attack (AOA) and departure characteristics nor experience in departure mode recognition and recovery.

The Naval Air Warfare Center Aircraft Division (NAWCAD) has been conducting departure flight-testing and demonstrations for the United States Navy and Marine Corps and Foreign Military Sales (FMS) customers since 1994. The departure demonstration flights have been designed to improve the F/A-18 pilot's awareness and understanding of impending departure cues, departure characteristics, and recovery procedures.[1] F/A-18 Fleet Departure Training Standardization Program was designed to expose the fleet F/A-18 pilot to high angle of attack flying qualities, departure modes, and recovery procedures. Since 2001, Naval Air Systems Command (NAVAIR) Departure Training Standardization Instructor Pilots (Stan IPs) from Air Test and Evaluation Squadron Two Three (VX-23) and United States Naval Test Pilot School (USNTPS) have been training and qualifying Fleet Replacement Squadron (FRS) Departure Training Instructor Pilots (IPs). Departure Training Instructor Pilots from the three Fleet Replacement Squadrons (two Navy and one Marine Corps) in-turn train the Replacement Pilots (RPs, F/A-18 student pilots) before they are assigned to an operational squadron.

Since becoming operational, several different Flight Control Computer (FCC) Operation Flight Programs (OFP) have existed in the fleet operational F/A-18 Hornets. Brief development history of these OFP versions that affected the United States Marine Corps and Navy F/A-18 Hornets are listed in Table I-1.[2] Until v10.7, most operation flight program changes did not affect the flying qualities or the flight characteristics of the aircraft. FCC OFP v10.7 was the first attempt to improve those areas.

As previously mentioned, twenty F/A-18 Hornets were lost due to out-of-control flight. It was projected that ten more would be lost during the remaining service life of the Hornet. In an attempt to prevent future loss of F/A-18 Hornets to out-of-control flight, NAVAIR contracted with the Boeing Company to provide a modified FCC OFP that provides improved resistance to and recovery from out-of-control flight, and improved redundancy management. The FCC OFP from v10.5.1 was modified and upgraded with control law architecture similar to that developed during the F/A-18E/F Engineering, Manufacturing, and Development (EMD) program.[2] FCC OFP v10.7 provides significant improvements in departure resistance, departure recovery, and enhanced maneuverability of v10.5.1.

FCC OFP v10.7 eliminated most of the departure flight regions, however, it did not completely eliminate departures in the F/A-18 Hornet. Therefore, the fleet pilots still require education in F/A-18 departure tendencies. With v10.7, changes in the F/A-18 Departure Demonstration syllabus had to be made. The following section will address specific FCC OFP upgrades and their effects on Departure Demonstration Syllabus. Significant part of the flight test was conducted to fine tune the spin entry procedure. This thesis will focus closely on the spin flight test results and recommendation for spin demonstration procedure changes.

Table I-1. F/A-18 FCC OFP Change History

FCC OFP Version	Released	Improvements
v8.3.3	1984	Production software version. MCP-701B processor.
v8.5	1992	Improved Cross Channel Data Link (CCDL) monitor. Otherwise, essentially identical to V8.3.3.
v10.1	1988	First version for MCP-701E processor, CCDL Fix, takeoff trim change, Built-In-Test (BIT) changes, Manual Spin Mode change, Rudder command rate limit.
v10.3	1991	Air data and AOA source error corrections for reconnaissance (RECCE) nose shape and eliminated coupled steering engagement transients.
v10.5.1	1996	Source error corrections for the Combined Interrogator Transponder (CIT) antenna; Automatic Carrier Landing System (ACLS); changes to AOA failure logic, air data sensor (ADS) failure logic, aileron and rudder actuator signal recovery; rudder toe-in logic; and takeoff trim.
v10.7	2003	V10.5.1 baseline with upgrades to improve high AOA departure resistance and maneuverability, OCF recovery, and redundancy management.

CHAPTER II
FLIGHT CONTROL COMPUTER CHANGE

Aircraft flying qualities are the result of merging the airframe aerodynamic characteristics with the flight control system (FCS) laws. At high angles of attack, interactions of airframe and control law become even more significant. A full knowledge of the overall aircraft flying qualities requires an understanding of both the bare airframe aerodynamics and the control law features. FCC OFP v10.7 was the first change to the FCC that significantly affected the flying characteristics of the F/A-18 Hornet. The intent was to use software changes alone, without any hardware changes, to improve the flying characteristics of the Hornet. In order to fully understand the changes made with v10.7, understanding of the basic F/A-18 flight control system is necessary. Appendix B describes the F/A-18 flight control system.

Issues with v10.5.1

Wing rock at high AOA

Over the years, the F/A-18 community recognized and documented several shortcomings of v10.5.1. For example, the angle of attack for the highest lift available (Cl_{max}) is approximately 35 degrees angle of attack. With v10.5.1, above Cl_{max} a mild Dutch roll could be present and the magnitude could increase with increasing angle of attack. Dutch roll is described as a combination of small roll and yaw at the same time about the aerodynamic center of the aircraft. Looking at the wingtip from the cockpit during a Dutch roll, one would see the wingtip move in an elliptical or circular motion. With v10.5.1, once stabilized at 38 to 42 degrees angle of attack, the aircraft would settle into a noticeable, sustained and bounded wing rock. The magnitude of wing roll would range from 20 to 60 degrees angle of bank (AOB). Roll control with v10.5.1 was precise through Cl_{max} and then lateral/roll authority decreased above 35 degrees angle of attack. Roll control became sluggish above 50 degrees angle of attack.[3] Since close-quarter air-to-air combat have been known to drive the F/A-18 above 35 degrees angle of attack, elimination of Dutch roll at high angles of attack was desired.

Quickly changing spin arrows and delayed arrow removal

When the F/A-18 spin logic determines the spin direction from the yaw rate during a sustained spin, arrows are displayed in the two Digital Display Indicators (DDIs) to show which direction the pilot should apply anti-spin control input (Figure II-1). Anti-spin control input involves moving the control stick laterally in the direction of the spin arrows. Normally, this direction is into the direction of the spin if the spin was up-right. With v10.5.1, spin arrows had been erroneous in two cases: Quickly Changing Arrows and Delayed Arrow Removal.

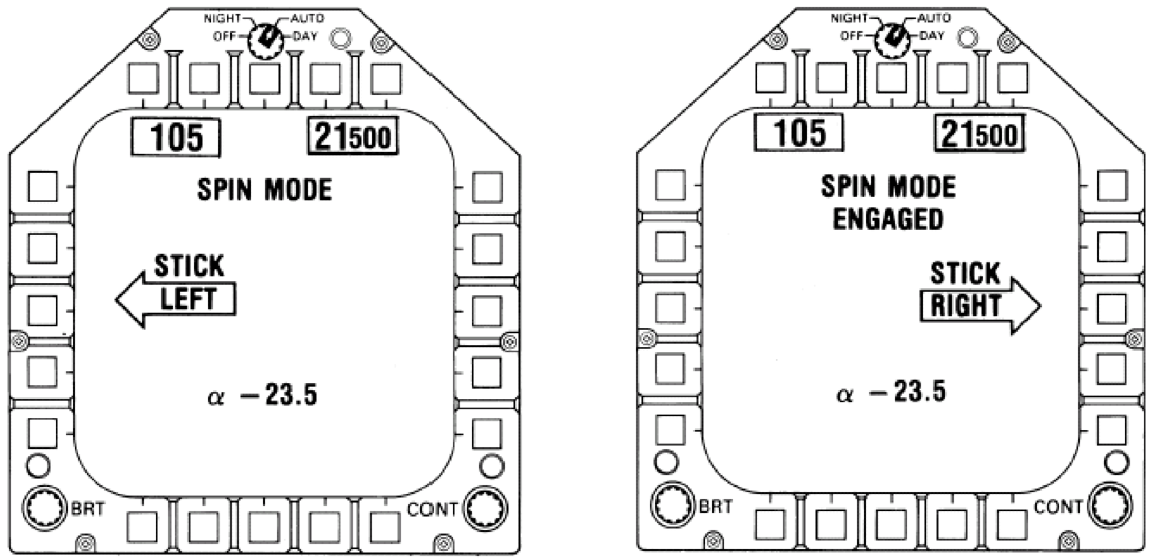


Figure II-1. Spin Mode Display on DDI

In the case of Quickly Changing Arrows, arrows had been known to instantaneously switch directions during spin recoveries.[2] These erroneous changes in arrows reduced pilot confidence in the system. It also delayed recovery due to incorrect pilot response: changing the lateral stick input as the pilot "chases" the changing arrows. With v10.5.1, pilots were trained not to "chase" the arrow by not moving the stick from its neutral position until the arrows were displaying steadily in one direction.

The other case was the Delayed Arrow Removal. In this case, the spin arrows remained illuminated despite the spin being clearly recovered.[2] This delay in removal of spin arrows from the DDIs caused the pilot to sustain the input and delayed recovery from the spin and caused re-departure or spin in the opposite direction. Therefore, pilots have also been trained to look outside the cockpit for indication of spin recovery, such as yaw rate ceasing, to remove anti-spin control input. The desired performance was to eliminate Quickly Changing Arrow and proper and timely removal of spin arrows when spin recovery was indicated.

Inadequate departure resistance for multiple-axis inputs

It is common for a fighter pilot to look over his/her shoulder then pull and roll to maneuver the aircraft in order to engage an enemy that is above and behind the fighter. With v10.5.1, there had been inadequate departure resistance for such multi-axis inputs when compared to contemporary fighters. In particular, a lateral and aft combined control inputs were known to cause departure from controlled flight. The desired performance was that the aircraft remain controllable for multi-axis control inputs the pilots considered common.

Low AOA rudder departures

During a “bug out” or a disengagement from an air-to-air engagement, the goal of the pilot is to separate as soon as possible while still maintaining situational awareness (SA) to the opponent. In order to separate quickly, a widely used technique is to unload the aircraft for quicker acceleration by pushing forward on the control stick and selecting maximum afterburner (MAX) for maximum acceleration. This forward stick control input generally resulted in about 0.5g push at angles of attack less than 10 degrees. In order to maintain visual on an opponent aft of the aircraft, another widely used technique is to yaw the aircraft using rudders to see beyond the two vertical tails. This combination of unloading and yawing the aircraft had been known to cause violent departure due to the increase and overload of the sideslip beyond flight control surface control authority. The departure resulted in a violent snap roll in the opposite direction of the yaw with high sideforces. The desired performance was that the aircraft remain controllable but still be able to maintain visual on opponents behind the aircraft.

Inadequate high AOA roll performance

With v10.5.1, F/A-18 exhibited inadequate high angle of attack roll performance. Relative to contemporary fighters, the F/A-18 with v10.5.1 had sluggish roll performance above 30 degrees angle of attack and worse above Cl_{max} of 35 degrees angle of attack. The two-seat F/A-18 with a longer canopy rolled more sluggishly than the single-seat F/A-18.[3] More modern contemporary fighter, such as the F/A-18E/F, has much improved roll performance in the 30-40 degree angle of attack range. High angle of attack roll performance becomes extremely important during a close-quarter air-to-air engagement. Therefore, the desired performance was that the F/A-18B/D (two-seat) with the new departure resistance control laws possesses same-or-better time-to-bank to 90 degrees characteristics as the F/A-18A/C (single-seat) with v10.5.1 control laws. In other words, the two-seat Hornet should maneuver as well as the single-seat Hornet in roll at high angles of attack.

Departure during rolls at low speed near 35 AOA

With v10.5.1, F/A-18 experienced multiple departures from controlled flight during roll maneuvers conducted at low airspeeds below 200 knots calibrated airspeed (KCAS) and between 30 to 35 degrees angles of attack. These departures normally occurred during air-to-air combat training at the top of an Immelmann-like maneuver. While inverted, as the pilot aggressively applies lateral/roll stick input to roll up-right while maintaining aft stick input to complete the Immelmann-like maneuver, the sideslip would build and the aircraft would depart violently in the opposite direction of the roll input. The aircraft was most prone to departure when configured with a centerline tank, especially for the two-seat aircraft. The departure was in the form of a roll reversal – the aircraft would suddenly and violently roll in the opposite direction of the pilot applied control input. Elimination of this roll reversal departure was also desired.

Delayed recovery from out-of-control flight

Several aircraft losses were attributed to delayed recovery from out-of-control flight. In particular, the F/A-18 possessed a Falling Leaf mode that was known to take a long time and significant loss in altitude for recovery. Falling Leaf occurred following post departure gyrations or spins and had been the most encountered fully developed departure mode for a symmetrically loaded F/A-18 with v10.5.1 and below. The Falling Leaf mode is characterized by repeated cycles of large, uncommanded roll-yaw motions which reverse direction every few seconds – resembling a leaf falling from a tree. At each reversal the aircrew would sense high sideforce accompanied by lightness in the seat near zero g. With v10.5.1, average altitude loss prior to indications of recovery was approximately 5,000 feet, with maximum altitude loss being approximately 12,000 feet. Even larger altitude loss had occurred because of the high rate of descent in excess of 20,000 feet per min.[3] Transient and quickly reversing spin arrows were also known to display during the Falling Leaf mode. Elimination of the Falling Leaf mode was highly desired and was the primary reason for v10.7 development.

Improvements with v10.7

As previously mentioned, v10.7 was developed primarily to enhance F/A-18 departure resistance, to enhance recovery from departure, and to improve maneuverability. Table II-1 lists several important upgrades to the Flight Control Computer Operation Flight Program that have affected the high angle of attack flying qualities and departure characteristics of the F/A-18 with v10.7.

Table II-1. Control Law Improvements with v10.7

	Departure Resistance	Departure Recovery	Maneuverability
Sideslip Feedback to Aileron and Differential Stabilators	●	●	
Sideslip Rate Feedback to Aileron and Differential Stabilators	●	●	
AOA Estimator for AOA > 35 degrees	●	●	●
Air Data Estimator for AOA > 30 degrees	●	●	●
Pedal Gain Change with Airspeed and AOA	●		
Pitch/Roll Inertial Coupling Limiters	●		
Spin Arrow Improvements		●	
Automatic Low-Rate Spin Prevention		●	
Pirouette Enhancer (Lateral Stick + Pedal)			●
Opposite Differential Stabilators for Roll			●

The most significant improvements were the addition of the sideslip and sideslip rate feedback and the estimators for the angle of attack and air data system. The following sections describe the Flight Control Computer Operation Flight Program v10.7 improvements.

Sideslip and sideslip rate feedback

The most significant upgrades to the Flight Control Computer Operation Flight Program were the incorporation of sideslip and sideslip rate feedback to the ailerons and differential stabilators. Previous to v10.7, the usual cause of departure in the Hornet was due to the increasing roll or yaw as a result of increasing sideslip. This increase in roll or yaw eventually overcame the control surface authority and resulted in departure from controlled flight. Therefore, the key to departure prevention in the Hornet was to minimize the sideslip with control surfaces before it became a problem. Since the F/A-18 lacks any external measuring equipment to measure the actual sideslip, estimates must be computed.

Estimates of sideslip and sideslip rate are computed for feedback to the ailerons and differential stabilators to enhance departure resistance at high angles of attack. Sideslip angle is computed in the control laws using both lateral acceleration and the integral of sideslip rate as a function of yaw rate, roll rate, angle of attack, lateral acceleration, and the pitch and roll attitudes. The attitudes are obtained from the Inertial Navigation System (INS), which must pass tests in an added monitor to ensure the validity of these data. The feedback is then sent to the ailerons, rudder, and stabilators via the FCC to improve the apparent sideslip stability. This apparent sideslip stability also benefits from the yaw and rolling moments from those surfaces to control sideslip at high angles of attack. The feedback is active when angle of attack is greater than 18 degrees and is scheduled with Mach number and compressible dynamic pressure.[2]

The sideslip rate feedback also works to stabilize the Dutch roll mode by damping the sideslip perturbations. The sideslip rate feedback is active for essentially the same flight conditions as the sideslip feedback. Sideslip rate is computed from stability axis yaw rate, lateral acceleration, true airspeed (TAS), and pitch/roll angles. The sideslip rate feedback is active when angle of attack is greater than 16 degrees and is scheduled with Mach number and compressible dynamic pressure.[2]

AOA estimator above 35 degrees AOA

An angle of attack estimator was added to provide an accurate signal beyond the physical angle of attack probe limit of 35 degrees true. This was primarily to ensure good sideslip damping performance during the falling leaf mode that has angle of attack swings to near 70 degrees. It is also used to improve roll performance and departure resistance at the higher angles of attack. This high angle of attack estimator signal is only used in the lateral directional control laws. The estimator works by integrating a computation of angle of attack rate that is derived from several variables: normal load factor, pitch rate, estimated angle of sideslip, roll rate, angle of attack, pitch angle, roll angle, estimated airspeed, and estimated airspeed rate of change. The integration is initiated when a probe hits its upper position limit. This integral is then added to a baseline angle of attack, which is the larger of the two true angle of attack probe signals when at least one probe is near its positive position limit of 35 degrees. To avoid integrator drift, the integral is slowly slaved to an independent angle of attack estimate based on stabilator position at higher angles of attack. The slave logic is disabled for the first 5 seconds of integration to improve accuracy.[2]

Air data estimator above 30 degrees AOA

When AOA is less than 30 degrees, control law true airspeed is set equal to true airspeed from the Air Data Computer (ADC). At high angles of attack the pitot pressure data from the probes degrade and accurate representation of the air data parameters cannot be provided based on the pitot pressure measurements. Therefore, at angles of attack greater than 30 degrees, the air data logic uses estimated values of true airspeed and dynamic pressure (Qc). The Air Data Estimator logic estimates the true airspeed; first, by using the normal force and gross weight from the mission computer and estimating the stabilator trim position. The stabilator trim position is computed by determining the local stabilator angle of attack, pitch rate, aircraft angle of attack, trailing edge flap deflection, downwash, and pitch acceleration. Then the aerodynamic normal force coefficient is calculated by adding the contribution due to the stabilator to the wing-body portion with the stabilator off. Dynamic pressure is then solved using normal force coefficient, normal force, and reference wing area. Mach number is then estimated by using this estimated dynamic pressure. Then the estimated Mach number is multiplied by speed of sound to estimate the true airspeed.[2] This new process of estimating the true airspeed and dynamic pressure ensures accurate estimation of sideslip and sideslip rate.

Pedal gain change with airspeed and AOA

In order to increase the departure resistance during the previously mentioned “bug out” scenario, rudder pedal gain schedule is changed to limit the amount of rudder authority available for low airspeed and low angle of attack pedal input. The rudder pedal force signal is air data scheduled to prevent excessive rudder commands that may build up the sideslip and sideslip rate beyond the vertical tail load limits. Pedal gain reduction is a function of airspeed and angle of attack, and is scheduled for airspeeds less than 240 KCAS or angle of attack less than 14 degrees.[2] For example, as the angle of attack decreases below 14 degrees at 210 KCAS, air data and angle of attack gain schedules is used to decrease the rudder gain, which decreases the rudder control surface deflection. In other words, if full rudder input was held and the angle of attack continued to decrease while airspeed stayed the same, rudder control surface deflection would decrease. The end result is increased departure resistance as the angle of attack decreases.

Pitch/roll inertial coupling limiters

Multi-axis control inputs, such as full nose up along with full roll command, caused excessive pitch/roll inertial coupling which lead to departure. This was prevented in v10.7 by automatically reducing the roll command when the magnitude of the pitch/roll inertial coupling exceeds a threshold. Pitch rate and roll rate limiter (PQ Limiter) reduces the roll command when the rudder being used to compensate for pitch/roll inertial coupling becomes large. This function helps to maintain controllable levels of inertial coupling when both roll and pitch are commanded simultaneously. The roll command begins to reduce when the rudder command due to pitch/roll inertial coupling exceeds 10 degrees, to a minimum of a 20% authority when the rudder command due to coupling exceeds 17 degrees.[2] This function works only in the nose up direction.

Pitch rate and roll rate clamp (PQ Clamp) is also incorporated to assure that pitch/roll inertial coupling remains controlled through the forward control input when both pitch and roll are commanded simultaneously. The roll command path is temporarily limited to a minimum of one-sixth of full deflection when a large and rapid pitch command is detected. The PQ clamp is removed at low altitude and high speeds where pitch rates are low due to load factor limits. It works for both forward and aft inputs, but is invoked sooner for aft inputs than forward inputs. The function is removed with time, using a washout filter with a 1.5-second time constant.[2] This allows for execution of pitch command followed by execution of roll command after 1.5 seconds when control stick is moved to full aft corners.

Spin arrow improvements

In v10.7, several improvements were made to the spin mode. Modifications were made to improve the accuracy of the spin arrow display, including earlier spin arrow removal during recovery. Spin arrows appear when lagged yaw rate exceeds 17 degrees per second, airspeed is below 120 KCAS ± 15 knots, and instantaneous yaw rate exceeds 17 degrees per second. Lagged yaw rate refers to average yaw rate over time (yaw rate filter time constant) and is used to quantify a sustain spin. Prior to v10.7, lagged yaw rate remained unchanged during spin arrow oscillations. This caused the spin arrows to quickly change directions although the spin was not sustained in either direction. In v10.7, lagged yaw rate is reset to zero when a spin arrow is removed to more accurately reflect the true spin direction in oscillatory cases.

Previously, the Automatic Spin Mode disengagement was designed to turn off a spin recovery command arrow when the product of yaw rate and lagged yaw rate falls below 225 deg^2/sec^2. In v10.7, the timely arrow removal function incorporated removing the arrows as instantaneous yaw rate decayed below 17 degrees per second, airspeed increased roughly above 239 KCAS, or lagged yaw rate decayed below 17 degrees per second.[2] This put less emphasis on the lagged yaw rate requirement and resulted in timely removal of spin arrow to properly indicate recovery from the spin.

During the v10.7 prototype evaluation, a re-departure occurred during a 90-degrees per second spin recovery.[4] One of the issues for this departure was that too much anti-spin aileron was being used that generates excessive adverse sideslip. Change was made to reduce the lateral stick gain to half in spin mode for yaw rate less than 40 degrees per second (full gain for yaw rates greater than 60 degrees per second) to help guard against re-departures and/or re-spin when the anti-spin control inputs were held too long.[2] Another issue during v10.7 prototype evaluation was that spin mode was engaged several times despite the pilot having his hands completely off the stick.[4] This was caused because the side forces were sufficient to move the stick in the direction of the arrow with spin arrows present. Since all feedback control is removed when spin mode is engaged, this situation had the potential to significantly delay out-of-control recovery. The previous threshold for spin mode engagement was ¼ inch of lateral stick movement. In order to avoid inadvertent spin mode engagement due to stick movement, v10.7 increased the threshold to ¾ inch lateral stick movement.[2]

At high angles of attack, roll command is translated to roll about the relative wind. This maneuver resembles a roll and yaw about the body axis. The yaw rate filter time constant is varied to prevent inadvertent spin arrows in such cases where the aircraft is known to have significant controllable yaw rate. In these cases, the filtering is done more heavily to delay the filtered yaw rate from reaching the 17 degrees per second threshold. There are three cases for heavier filtering: when the enhanced high angle of attack roll maneuvering is active; when lateral stick and pedal are deflected in the same direction such that the sum is greater than 150% (full pedal and full lateral stick being 200%); and when lateral stick and/or pedal are deflected greater than 67% combined and in the direction of an established roll.[2] The simplified spin mode yaw rate lag filter time constant logic is shown in Figure II-2.

Automatic low-rate spin prevention

Automatic Low-Rate Spin Prevention control law was added to help remove instances of prolonged low-rate spins. This logic suppresses a spin mode with yaw rate in the 30 to 40 degrees per second range that can potentially occur without activating the spin recovery command arrows. The suppression of low-rate spin prevents roll/yaw inertial coupling from generating a nose up pitching moment that cannot be countered with full nose down stabilator deflection. The function automatically applies anti-spin controls (differential aileron and differential stabilator with the spin) when the conditions exist for the low-rate spin. The low-rate spin is defined by yaw rate greater than 20 degrees per second in combination with full nose-down stabilator command by the longitudinal feedback. This logic is active for only upright spins (positive load factors only) to avoid inaccuracies in the angle of attack signal that are typical in out-of-control flight.[2]

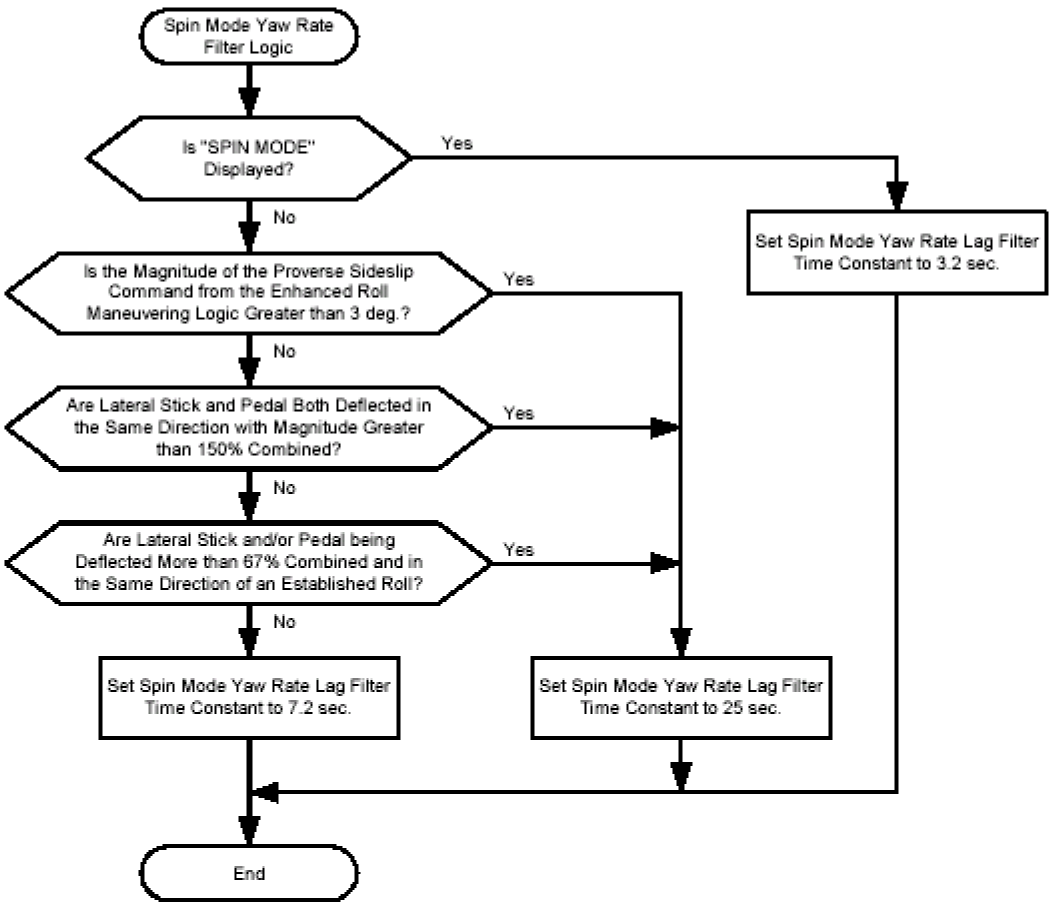


Figure II-2. Spin Mode Yaw Rate Lag Filter Time Constant Logic

Pirouette enhancer

Pirouette enhancer was added to allow pilots to obtain a boost in roll performance at high AOA and low speeds to obtain a pirouetting motion. Pirouetting motion is described as yawing of the aircraft about its aerodynamic center to quickly swap the nose position 180 degrees. When the criteria are met, the flight control system recognizes the pilot's desire to rapidly reverse aircraft heading and displaces control surfaces appropriately. The abrupt but controlled heading reversal is obtained by temporarily adding proverse sideslip when both the lateral stick and pedal are deflected in the same direction. The function is removed at higher airspeeds (compressible dynamic pressure above 150 pounds per square foot (psf), roughly 260 KCAS), is full on for lower airspeeds (compressible dynamic pressure less than 75 psf, roughly 150 KCAS), and is only active for angles of attack greater than 18 degrees (best performance near 45 degrees angle of attack).[2] Spin display logic (yaw rate filter time constant) is modified during a commanded pirouette to prevent nuisance spin indications (Figure II-2). Basically, the display of spin arrows is suppressed during an intended pirouette maneuver for up to 25 seconds while the pirouette control inputs are held. Pirouetting motion can be stopped at the desired heading by applying full lateral stick and pedal in the direction opposite that which initiated the maneuver.

Opposite differential stabilators for roll

The differential stabilator is deflected opposite the intended roll direction at high angles of attack and low airspeed to allow that surface to provide added yawing moment for enhanced roll coordination and performance. The benefit is that the aileron deflection can be increased to provide a net improvement in the coordinated roll performance at high angles of attack. The aileron-to-stabilator ratio begins to reduce above 30 degrees angle of attack, and reverses above 36 degrees angle of attack.[2]

Improvements made in v10.7 allows sideslip and sideslip rate feedbacks to become active to damp out sideslip oscillations and minimize left/right residual motion above 20 degrees angle of attack. From 25 to 35 degrees angle of attack, roll performance gradually decreases with increasing angle of attack. Above 25 degrees angle of attack, pedal and lateral stick inputs provide similar responses. Above 35 degrees angle of attack and at low airspeed the roll performance is essentially constant. From 35 to 55 degrees angles of attack, combined lateral stick and pedal inputs produce enhanced roll performance compared to individual control input.[3]

As a result of v10.7, departure resistance of the F/A-18 has increased and very aggressive maneuvering is possible. Yaw stability augmentation significantly reduced the likelihood of departure throughout the envelope. Addition of sideslip and sideslip rate feedback as well as differential stabilator for yaw rate generation, improved inertial coupling limiter and rudder deflection limits in the low angle of attack region, increasing the departure resistance. Single axis maneuvering is extremely departure resistant. Multiple-axis maneuvering, roll or yaw input combined with aft stick input is also very resistant to departure. The F/A-18 has become very stable and controllable throughout most of the operational flight envelope. However, it is still departure prone in some flight regimes which pilots must be aware of to avoid inadvertent departures. The aircraft is still susceptible to departure when roll or yaw input is combined with forward input, particularly from high angles of attack and greater than 0.6 Mach number. Cross control inputs are also very departure prone above 0.6 Mach number and low angles of attack. Directional stability can be weakened due to carriage of stores or lateral weight asymmetries, particularly at high g and high angles of attack above 20 to 25 degrees. The results of extensive v10.7 flight test and comparison to v10.5.1 are shown on Table II-2.[5]

Table II-2. v10.5.1 and v10.7 Departure Prone Region Comparison

	α (°)	Lateral only	Pedal only	Lateral with Pedal	Lateral against Pedal	Lateral with Pedal and Fwd	Lateral against Pedal and Fwd	Lateral with Pedal and Aft	Lateral against Pedal and Aft	Lateral + Fwd	Lateral + Aft	Lateral to Max Rate then Aft
v10.5.1	45					Departure	Mild			Departure		
	40					Departure	Mild			Mild		
	35	Mild				Departure	Mild			Mild		
	30	Departure	Departure	Departure		Departure						Mild
	25					Mild						
	20		Mild			Mild						Mild
	15		Departure	Mild		Mild						Departure
	10		Departure	Mild		Mild		Mild	Departure		Departure	Departure
	5		Mild			Mild		Departure	Departure		Departure	Departure
	0		Departure			Departure	Mild	Departure	Departure	Mild	Departure	Departure
	-5		Departure			Departure	Departure	Departure	Departure	Mild	Departure	Departure
	-10		Mild	Mild		Departure	Departure	Departure	Departure	Departure	Departure	Departure
v10.7	45					Mild	Mild					
	40					Mild	Mild					
	35					Mild	Mild					
	30					Mild						
	25					Mild						
	20					Mild						
	15											
	10											Mild
	5					Mild						Departure
	0					Mild	Mild			Mild		Departure
	-5					Departure	Mild			Mild		Departure
	-10					Departure	Departure			Departure		Departure

(blank) = No Departures   Mild = Mild Departures / Oscillations   Departure = Departure

CHAPTER III
DEPARTURE DEMONSTRATION CHANGES DUE TO v10.7

Although v10.7 significantly increased the departure resistance of the F/A-18, it did not completely eliminate departures. Therefore, pilots must still be aware of these departure prone flight regions and must know what to do in out-of-control flight. The departure demonstration was designed to improve the F/A-18 pilot's awareness and understanding of impending departure cues, departure characteristics, and recovery procedures. Due to the changes in flight characteristics with v10.7, the departure demonstration flight syllabus needed to be updated. Appendix C and D are the departure demonstration flight cards for v10.5.1 and v10.7 respectively. Notable changes are in high AOA static stability demonstration, elimination of low AOA rudder departure demonstration, and significant changes in automatic spin recovery mode (ASRM) demonstration. In addition, notable changes in departure characteristics are experienced during vertical departures.

No More Wing Rock

An aggravating characteristic with v10.5.1 was the uncommanded wing rock particularly with the two-seater F/A-18 with centerline tank if angle of attack is held between 38 to 42 degrees. This uncommanded wing rock was defined as a bounded lateral and directional oscillation, having sideslip excursions near ±15 degrees, roll rate oscillations of ±40 degrees per second, yaw rate oscillations of ±8 degrees per second and bank angle oscillations of about ±40 degrees. The oscillations subside as angle of attack is increased to full aft stick (FAS). The same 1g-stall maneuver in the v10.7 two-seat F/A-18 with centerline tank results in no wing rock, as angle of attack is held for greater than 10 seconds in the 38 to 42 degree region.[6] Therefore, the wing rock demonstration portion of the flight was deleted.

No More Low AOA Rudder Departures

The "bug out" scenario departure condition with v10.5.1 existed near zero angle of attack and low airspeeds for full rudder pedal input (yielding approximately 10 degrees of rudder). The departure was caused by run-away sideslip that built to a maximum of nearly 30 degrees when the aerodynamic rudder yaw power exceeded the available aircraft directional stability. As the resultant sideslip exceeded 20 degrees, large moments resulted on the aircraft to create uncommanded roll and yaw rates. Roll rate peaked to approximately 150 degrees per second and yaw rate peaked to approximately 60 degrees per second, resulting in a severe departure.[6]

With v10.7, in the two-seat Hornet with centerline tank configuration, approximately 13 degrees of maximum sideslip is generated with the full pedal input near zero angle of attack.[6] This maximum sideslip is not large enough to cause a run-away sideslip buildup. Maximum yaw rates are also low and well controlled and only a slow roll rate is generated in the direction of the pedal input. Control inputs that resulted in low angle of attack rudder departure with v10.5.1, result in a controlled flight with no large roll or yaw rates with v10.7. Therefore, the Low AOA Rudder Departure demonstration was deleted from the flight syllabus. The aircraft nose movement from a pedal input at low angle of attack and low airspeeds still remains sufficient to look behind the aircraft and keep visual of the opponent.

Mild Vertical Departures

A major focus of the test program was to assess the recovery from vertical departures, also known as tailslide maneuvers. The tailslide maneuver replicates the condition most susceptible to falling leaf entry based on observations from fleet out-of-control flight events. The set up for the maneuver begins at 30,000 feet and 300 KCAS. A gradual pull to vertical (90-degrees nose up) is made. The tailslide begins as the aircraft peaks in altitude and zero airspeed. Recovery procedure, according to Naval Air Training and Operating Procedures Standardization (NATOPS), is to let the aircraft recover from the departure on its own until the "AOA and yaw tones removed, sideforces subsided, and airspeed increasing through 180 KCAS."[3] Recovery to controlled flight was then initiated by increasing the power and pulling the nose to the horizon to minimize the altitude loss. The best chance of falling leaf motion observed in fleet cases has been with the aircraft banked to either side at the point where airspeed is lost. Many variations of the tailslide technique and aircraft loadings were tested during v10.7 evaluation to ensure that the falling leaf entry case was adequately covered.[6]

A total of 62 tailslides were performed during the v10.7 evaluation and many more have been performed to date during departure demonstration flights. There were many cases where the departure conditions may have resulted in severe motion with v10.5.1, but no sustained out-of-control motion, such as sustained spin or sustain falling leaf, was observed with v10.7. In general, any rolling and yawing motion would quickly damp whenever the angle of attack cycled high during the oscillations. This is primarily a result of sideslip and sideslip rate feedback driving the ailerons and differential stabilators to damp the roll and yaw motions. With v10.5.1, departure and recovery motions were unpredictable and severe while the altitude loss generally ranged from 8,000 feet to 12,000 feet with some extreme cases exceeding 20,000 feet.[6] With v10.7, departure and recovery motion have become very mild and predictable while the altitude loss has consistently ranged from 8,000 feet to 10,000 feet. Vertical departure and recovery motion with v10.7 could be categorized in two typical examples: upright recovery and inverted recovery.

Upright Recoveries

The most common tailslide recovery is when the aircraft pitches forward as it descends on its tail then settles upright pointed nose low. This motion produces a large positive angle of attack swing, which engages the sideslip and sideslip rate feedback that then dampens any roll and yaw motion. The aircraft nose typically falls straight down with a large nose-down pitch rate but nose pitch beyond straight down to inverted is very rare. Usually, the nose pitches over quickly but settles around 60 to 80 degrees nose low. This pitch over is due to the angle of attack feedback that has been part of the flight control logic prior to v10.7 and remains unchanged. Angle of attack feedback is engaged if the aircraft is above 22 degrees angle of attack with no aft stick input. Once engaged, angle of attack feedback automatically increases the nose down stabilator command until the aircraft is below 22 degrees angle of attack. Once below 22 degrees angle of attack, angle of attack feedback is removed and the aircraft seeks 1g flight. Any sideslip oscillation, as long as positive angle of attack is maintained, is quickly damped by large aileron deflections and differential stabilator with no sustained out-of-control motion.

In some cases, a large sideslip is generated as the aircraft begins to descend – a sign that the aircraft is coming down on its side. These "sideslides" were believed to be the most effective means in generating falling leaf motion with v10.5.1. In most cases, the angle of attack starts off negative at the peak – a sign the aircraft is falling on its back. The aircraft then pitches down and yaws the aircraft to the left or right with positive angle of attack as the airspeed increases. The v10.7 sideslip and sideslip rate feedback quickly kicks in to dampen the sideslip oscillation by quickly deflecting the ailerons.[6] These aileron spikes are very common during the tailslide recoveries, usually going in the opposite direction before settling. Differential stabilators are also used and effective in damping any yaw. Any roll and yaw motion quickly damps and control is regained as airspeed increases.

Inverted Recoveries

If the aircraft peaks out beyond the 90-degrees vertical position, there is a tendency for the aircraft to fall on its back inverted. Sometimes the aircraft would end up inverted following the large initial nose pitch down. Usually, recovery is slightly delayed if the aircraft happens to settle inverted out of the tailslide. The reason the inverted case takes longer is because the sideslip and sideslip rate feedbacks are only active at positive angle of attack and effective at high angles of attack. Once inverted, the aircraft typically yaws and rolls to one side with moderate yaw rate (near 30 degrees per second) while the aircraft is inverted. This moderate yaw rate is sometimes large enough to briefly display the spin arrows. However, once the kinematic component of yawing and rolling motion places the aircraft in an upright position (positive angle of attack) after about 90 degrees of yaw and roll, sideslip and sideslip rate feedbacks become active and immediately damp out any rolling and yawing motions to recover the aircraft. Since the F/A-18 has a natural dihedral tendency to flip upright on its own, moderate yaw rate dwell while inverted is not a cause for concern. If any thing, it makes the benign v10.7 vertical departure demonstration more enjoyable.

Overall, F/A-18 with FCC OFP v10.7 successfully allowed for a consistent and rapid recovery from nose-high zero-airspeed flight, which was the prime objective of the flight control software development program.

Effects on Automatic Spin Recovery Mode Demonstration

Automatic Spin Recovery Mode Demonstration is used to expose aircrew to F/A-18 sustained yaw rate environment, spin mode displays, and recovery procedures. The F/A-18 exhibits four spin modes: low yaw rate, intermediate yaw rate, high yaw rate, and inverted.[3] Table III-1 describes these spin modes. All four types of spins are recoverable with proper anti-spin control input: full lateral stick input into the direction of steady arrow and holding until yaw rate ceases. The main goal of the demonstration is for the aircrew to properly recover from a fully developed spin. In order for this demonstration to be successful, ability to enter a sustainable but recoverable spin is obviously a requirement. With v10.5.1, this was easily done by stalling the aircraft, splitting the thrust, and introducing pro-spin control input as shown in Appendix C. However, with v10.7, technique modifications were necessary because the control law changes prevented the v10.5.1 technique from generating enough yaw rates to display the command arrows.

Stalling the aircraft is accomplished by holding full aft stick. With v10.5.1, lateral directional stability is degraded with full aft stick to a point where sufficient yaw rate is generated without pro-spin input in some cases. Pro-spin input with v10.5.1 was lateral stick opposite the direction of the spin. With v10.5.1, less than one inch of pro-spin lateral input was required. This one inch of lateral input is not enough to deflect the ailerons to create any roll, especially at high angles of attack. However, the small position differences (differential) of the stabilators create enough control surface drag to yaw the aircraft in the opposite direction of the lateral control stick input. With longitudinal stick already at full aft, this, along with Military/Idle throttle split, generates enough yaw rate to sustain a fully developed spin within one turn. For v10.5.1 spin demonstration, it was important to maintain full aft stick during the spin. If the stick came off the aft stop, the angle of attack would decrease, followed by decrease in yaw rate, and recover from the spin automatically. Therefore, it was necessary to apply anti-spin control input while maintaining full aft stick. The normal spin recovery procedure calls for neutralizing the stick first then applying lateral stick with the spin arrow.

Because v10.7 greatly improved the high angle of attack stability of the F/A-18, the same procedures for spin demonstration could not be used. Extensive flight test program was conducted to properly demonstrate a sustained spin and reinforce the recovery techniques.

Table III-1. F/A-18 Spin Modes

Spin Mode	Likely Entry Condition	Mode Recognition	Rate of Descent
Low Yaw Rate	Large sustained control inputs at high AOA. Maneuvering above AOA limits for lateral weight asymmetries > 6,000 ft-lbs.	Lack of response to forward stick with AOA around 50 to 60 degrees and low yaw rates (0 to 40 deg/sec). Not violent or disorienting.	Approx. 20,000 ft/min, as much as 5,000 ft lost per turn.
Intermediate Yaw Rate	Maneuvering above AOA limits for lateral weight asymmetries.	Oscillatory in pitch and roll with AOA from 40 to 80 degrees and yaw rates from 20 to 80 deg/sec. Cockpit sideforces may reach 1g and motion can be disorienting. May roll while spinning.	As high as 21,000 ft/min with approx. 1,500 ft lost per turn.
High Yaw Rate	Maneuvering above AOA limits for lateral weight asymmetries > 18,000 ft-lb.	Smooth flat spin motion with AOA from 80 to 90 degrees and yaw rates > 100 deg/sec. Longitudinal force (eyeballs out) up to 3.5g. May be more oscillatory with external stores.	Averages 18,000 ft/min, 1,000 – 1,500 ft lost per turn.
Inverted	Sustained full pro-spin controls. (highly unlikely)	AOA approx. –50 degrees and yaw rates approx. 30 deg/sec.	Approx. 21,000 ft/min, 3,500 ft lost per turn.

CHAPTER IV
SPIN DEMONSTRATION PROCEDURE FLIGHT TEST

The goal of the spin entry procedure evaluation was to develop a simple and repeatable procedure to enter a sustained spin with spin arrows displayed long enough to practice the NATOPS spin recovery procedure. During v10.7 evaluation, Manual Spin Recovery Mode (MSRM) spin entry technique was used extensively to achieve repeatable spin entries with yaw rates up to 90 degrees per second. Manual Spin Recovery Mode is a selectable back-up mode that can be activated if no spin arrows are displayed and full control authority is desired to arrest the spin. This mode disables the normal flight control feedbacks and provides full surface authority through the stick and pedal. Full deflection pro-spin rudder, differential aileron, differential stabilator, and asymmetric thrust were used to enter spins. As soon as the target yaw rate was achieved, Manual Spin Recovery Mode was de-selected which returned the aircraft to normal Control Augmentation System (CAS) mode. Spin recovery was accomplished either with neutral controls in normal CAS mode, or, if spin arrows were displayed, recovery was accomplished via the Automatic Spin Recovery Mode by deflecting lateral stick into the direction of the spin arrows. Although Manual Spin Recovery Mode spin entry technique repeatedly yielded sustained spins with display of spin arrows, use of Manual Spin Recovery Mode was not desirable since inexperienced aircrew may become too disoriented to de-select the Manual Spin Recovery Mode switch during the maneuver.

More than ten Automatic Spin Recovery Mode spins were conducted during v10.7 evaluation and many more were conducted after the formal test program was completed. Aircraft used for testing were aircraft with no known roll or yaw tendency due to radome effects. Vortices generated by imperfections on the radome have known to affect the directional stability of the aircraft. These vortices cause the aircraft to yaw and roll to one direction at high angles of attack. Static and accelerated radome checks, as outlined in Appendices C and D, were conducted on all test aircraft prior to spin testing. No directional bias existed for all test aircraft.

Initial setup for the new spin procedure would be the same as the old procedure with v10.5.1 – start at 150 KCAS and 35,000 feet, slow the aircraft to 35 degrees angle of attack, smoothly apply full aft stick, and split the throttles. Throttles remained split until the completion of recovery from the spin – until the yaw rate ceased. In order to generate enough yaw rate, pirouette inputs would be used initially to yaw the aircraft with v10.7. Once enough yaw rate is generated to satisfy the spin mode logic, the spin arrows are suppressed for 25 seconds while the pirouette inputs are held. Therefore, in order to display the spin arrows earlier than 25 seconds, pirouette control inputs would have to be neutralized (centered) once enough yaw rate is generated. Flight tests were conducted to determine the magnitude of asymmetric throttle and duration of pirouette inputs. First flight (Flight 1352) to provide data for determining an appropriate technique was conducted on February 11, 2003. Flight 1352 completed four attempts at Automatic Spin Recovery Mode spin entry procedures. The result of four spin attempts from Flight 1352 is shown in Table IV-1. Count for the turns started when the pirouette control inputs were applied and 360 degrees of aircraft yaw constituted as one turn.

Record 1-28 and 1-29 generated enough yaw rate and lagged yaw rate (greater than 17 degrees per second) to display spin arrows. However, the arrows disappeared immediately when the stick was moved just an inch into the arrow. These two brief displays of spin arrows were not long enough to properly train the aircrew.

Second flight (Flight 1354) to provide data for Automatic Spin Recovery Mode spin procedure was conducted on February 12, 2003. Only two attempts were made and results are shown in Table IV-2. Record 2-27 attempt did not display the spin arrows since the lagged yaw rate did not achieve the required 17 degrees per second. Record 2-28 resulted in display of spin arrows approximately a half turn after the controls were neutralized but they were only displayed very briefly. The test pilot felt that the arrows were removed before the pilot had a chance to analyze and determine if lateral stick input with the arrow was required for recovery. This did not meet the training objectives of the spin demonstration.

Third flight (Flight 1356) with Automatic Spin Recovery Mode spin data was conducted on February 20, 2003. Six attempts all resulted in the display of spin arrows. MAX/Idle splits were used for all six attempts along with holding the pirouette control inputs for one and a half turns prior to neutralizing the inputs. Each spin generated a repeatable yaw rate of approximately 50 degrees per second. The results are shown in Table IV-3. All the spin entry techniques involved splitting the throttles followed by pirouette inputs except for Records 3-11 and 3-15. For Records 3-11 and 3-15, pirouette inputs were made followed by throttles split. The spin results were about the same, but moving the throttles while holding the pirouette inputs made the maneuver more difficult to perform.

While the pirouette inputs were held, the nose tended to oscillate between 15 to 50 degrees nose low while angle of attack fluctuated around 60 degrees ± 10 degrees. Once the inputs were removed after 1.5 turns (540 degrees), spin arrows appeared a half turn (180 degrees) later. Spin arrows were displayed long enough to accomplish the training objectives of executing spin recovery procedures. When anti-spin control input was applied into the direction of the spin arrows, yaw rate seemed to cease almost immediately - within 30 degrees of turn. Removal of the spin arrows seemed to coincide with the ceasing of the yaw rate. The test pilot commented that the removal of the spin arrows seemed much quicker than with v10.5.1.

Table IV-1. ASRM Spin Procedure Development (February 11, 2003)

Record	Throttle Split	Pirouette Inputs Duration (Turns Held)	Spin Arrow	Max Yaw Rate (deg/sec)	Max Lagged Yaw Rate (deg/sec)
1-26	MIL/Idle	1	No	40	12
1-27	MAX/Idle	1	No	48	15
1-28	MAX/Idle	1.5	Yes	N/A	N/A
1-29	MAX/Idle	1.5	Yes	N/A	N/A

Table IV-2. ASRM Spin Procedure Development (February 12, 2003)

Record	Throttle Split	Pirouette Inputs Duration (Turns Held)	Spin Arrow	Max Yaw Rate (deg/sec)	Max Lagged Yaw Rate (deg/sec)
2-27	MIL/Idle	1.5	No	43	16.9
2-28	MAX/Idle	1.5	Yes	N/A	N/A

Table IV-3. ASRM Spin Procedure Development (February 20, 2003)

Record	Throttle Split	Pirouette Inputs Duration (Turns Held)	Spin Arrow	Max Yaw Rate (deg/sec)	Max Lagged Yaw Rate (deg/sec)
3-8	MAX/Idle	1.5 Right	Yes	53	N/A
3-9	MAX/Idle	1.5 Right	Yes	52	N/A
3-10	MAX/Idle	1.5 Left	Yes	49	N/A
3-11	MAX/Idle	1.5 Left	Yes	49	N/A
3-14	MAX/Idle	1.5 Right	Yes	50	N/A
3-15	MAX/Idle	1.5 Right	Yes	46	N/A

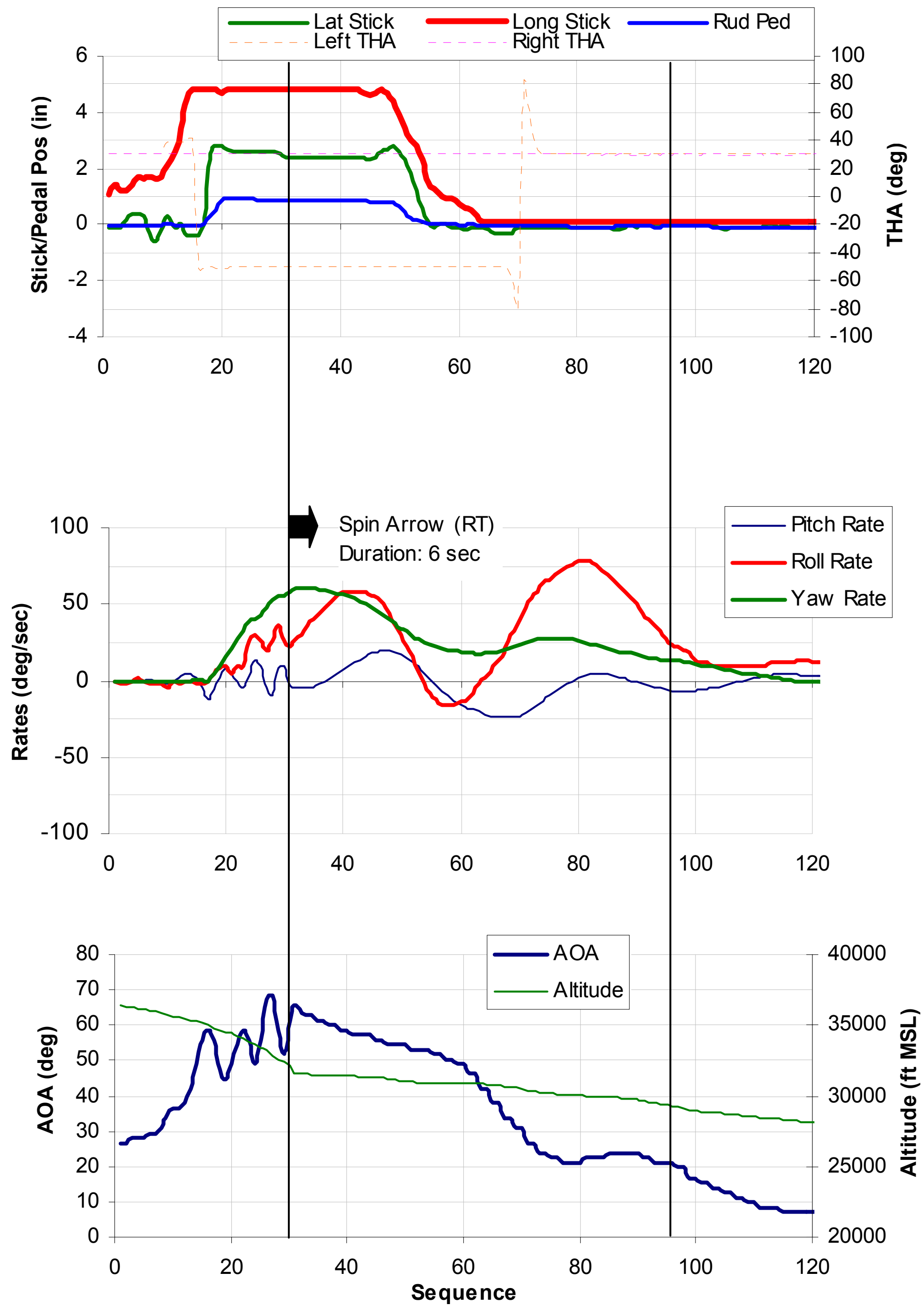
Two out of the six attempts were completed without the application of anti-spin control input. For Record 3-14 spin, once the pirouette inputs were removed, spin arrows displayed within a half of turn and remained displayed for approximately 9 more seconds or ¾ of a turn (270 degrees). Yaw rate slowed after five seconds. Yaw rate ceased and spin arrows disappeared after 9 seconds. Altitude loss while the spin arrows displayed was approximately 2,000 feet. Once the yaw rate ceased, throttles were placed to idle and recovery from the dive was made without any problems. Splitting the throttles after the pirouette inputs was used for Record 3-15 spin. The spin results were similar to Record 3-14, except that the arrows stayed on for approximately 5 seconds. The test pilot felt that 5 to 9 seconds would be enough time to accomplish the spin recovery objectives of the spin demonstration. Once again, splitting the throttles following the pirouette inputs were deemed to difficult since both hands were typically used to maintain full aft stick and hold the pirouette inputs.

As previously mentioned, more tests were conducted after the formal v10.7 evaluation to fine-tune the spin entry procedures. Flight test results from July 16, 2003 are shown on Table IV-4 and Figures IV-1 through IV-5. All spins were conducted using MAX/Idle throttle split. Two different spin entry methods were compared: full pirouette inputs until spin arrows are displayed and full pirouette inputs for 1.5 turns. Five different spin recovery methods were also compared: neutralizing the controls while synchronizing the throttles; neutralizing the lateral stick input while holding full aft stick; anti-spin lateral stick input with spin arrow while holding FAS; simply neutralizing the controls; and neutralizing the controls then lateral stick input with spin arrow. Spin 4 was aborted due to a nuisance fuel tank pressure caution. Its results are not presented as data.

Table IV-4. Spin entry and recovery method comparison (July 16, 2003)

Figure		Spin Entry Method	Spin Recovery Method
IV-1	Spin 1	Full Pirouette until Spin Arrow	Neut. Control / Synch Throttles
IV-2	Spin 2	Full Pirouette for 1.5 Turns	Hold FAS / Lat Stick & Rudder Neut.
IV-3	Spin 3	Full Pirouette for 1.5 Turns	Hold FAS / Lat Stick w/ Spin Arrow
IV-4	Spin 5	Full Pirouette for 1.5 Turns	Neut. Controls
IV-5	Spin 6	Full Pirouette for 1.5 Turns	Neut. Controls / Lat Stick w/ Arrow

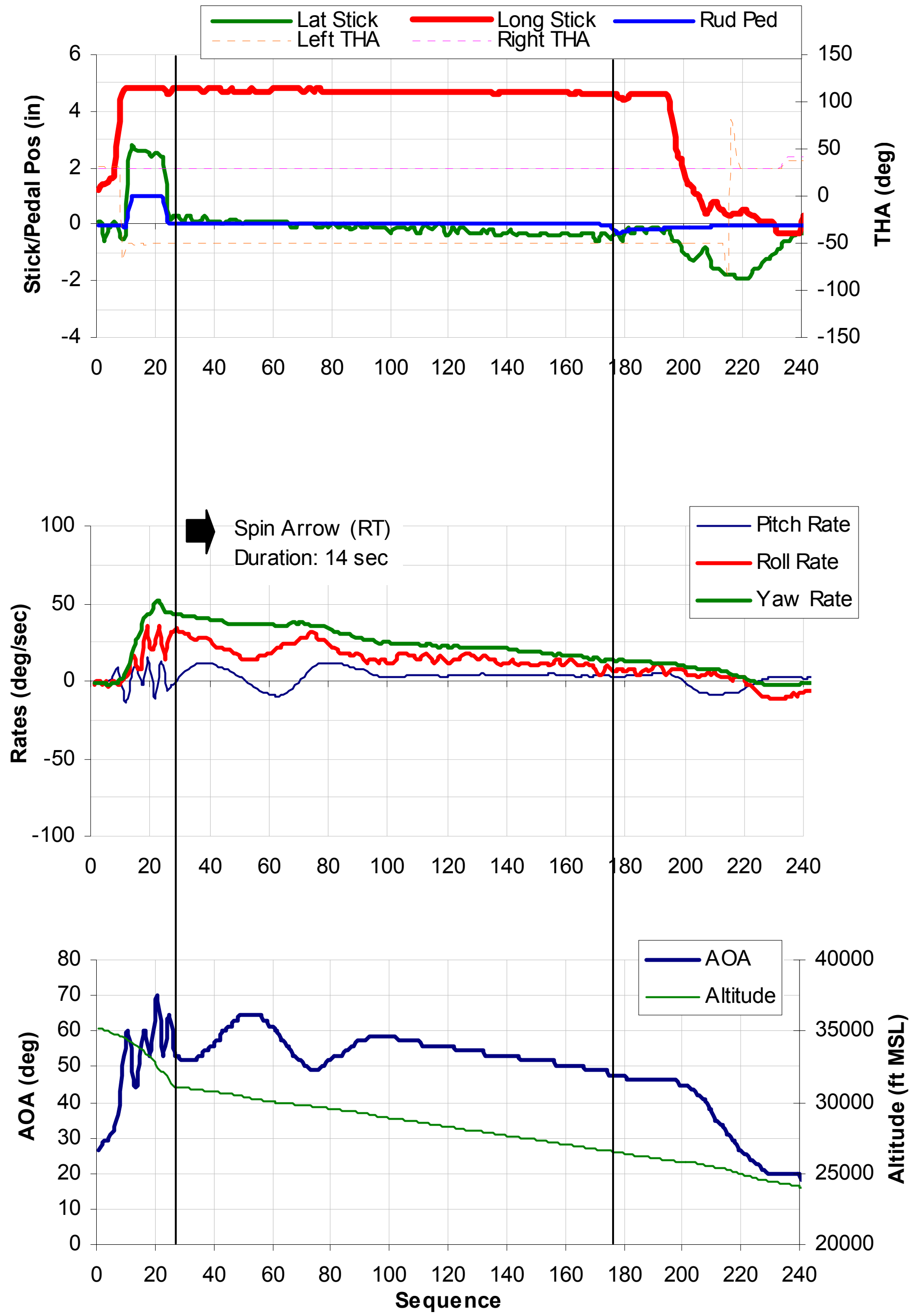
Entry Technique: Full Pirouette until Spin Arrows
Recovery Technique: Neutralize Controls / Both Throttles to Idle



Note: 1. Time scale is different prior to and after the spin arrow.
2. 10 sequences per second while the spin arrow is displayed.

Figure IV-1. ASRM Spin Procedure Development (Spin 1, July 16, 2003)

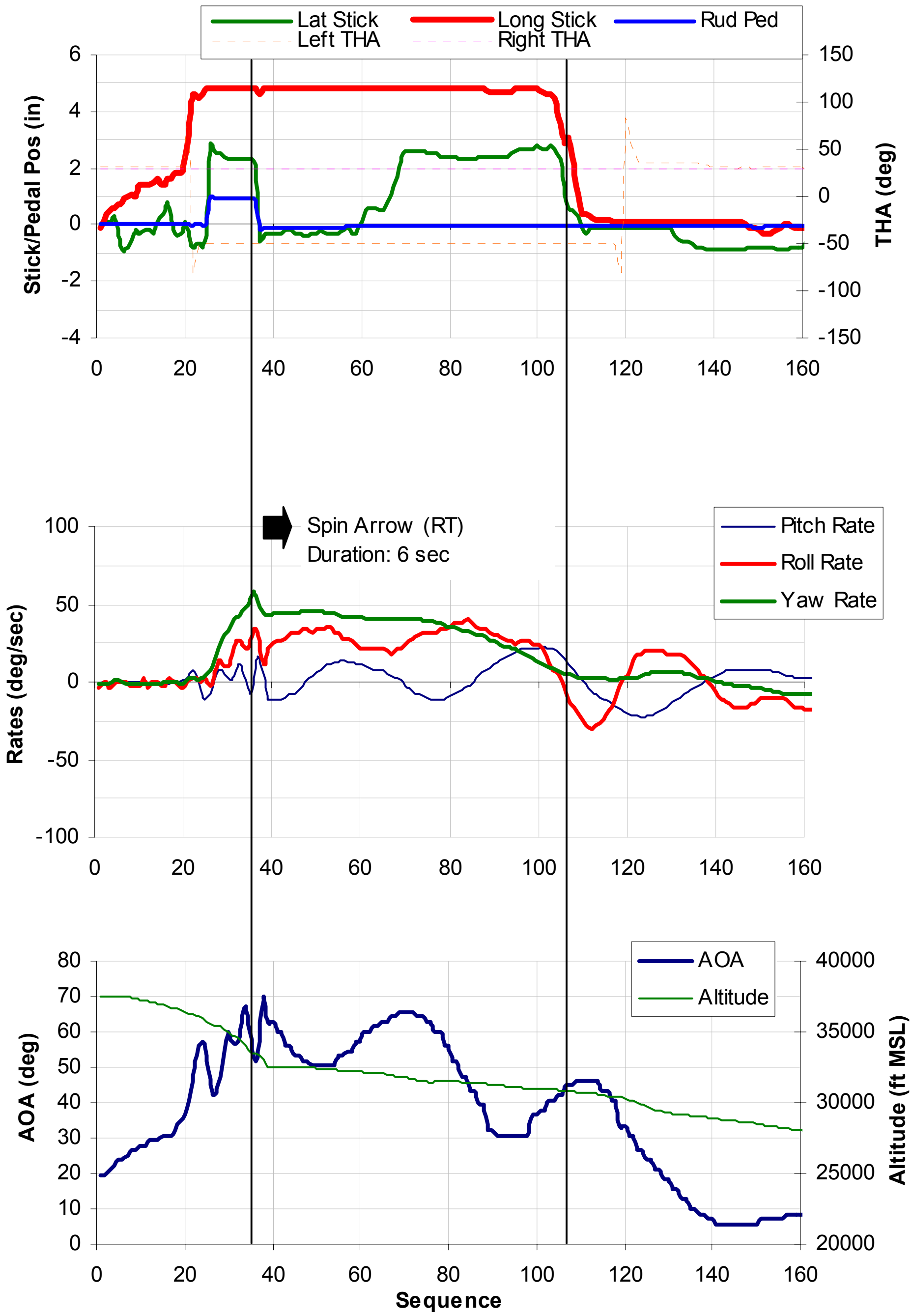
Entry Technique: Full Pirouette for 1.5 Turns
Recovery Technique: Hold FAS / Lat Stick and Rudder Neutral



Note: 1. Time scale is different prior to and after the spin arrow.
2. 10 sequences per second while the spin arrow is displayed.

Figure IV-2. ASRM Spin Procedure Development (Spin 2, July 16, 2003)

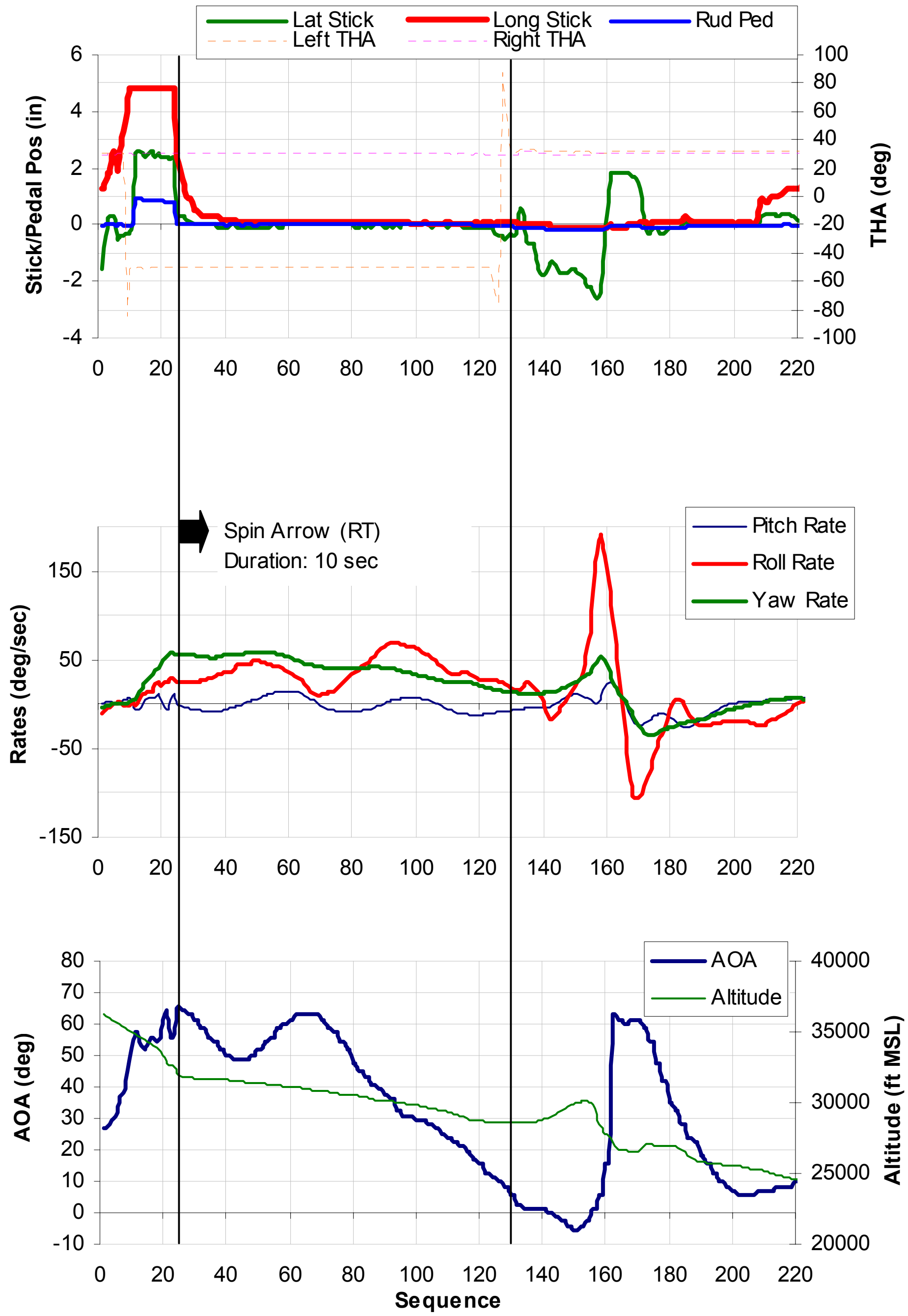
Entry Technique: Full Pirouette for 1.5 Turns
Recovery Technique: Hold Full Aft Stick / Lat Stick with Arrow



Note: 1. Time scale is different prior to and after the spin arrow.
        2. 10 sequences per second while the spin arrow is displayed.

Figure IV-3. ASRM Spin Procedure Development (Spin 3, July 16, 2003)

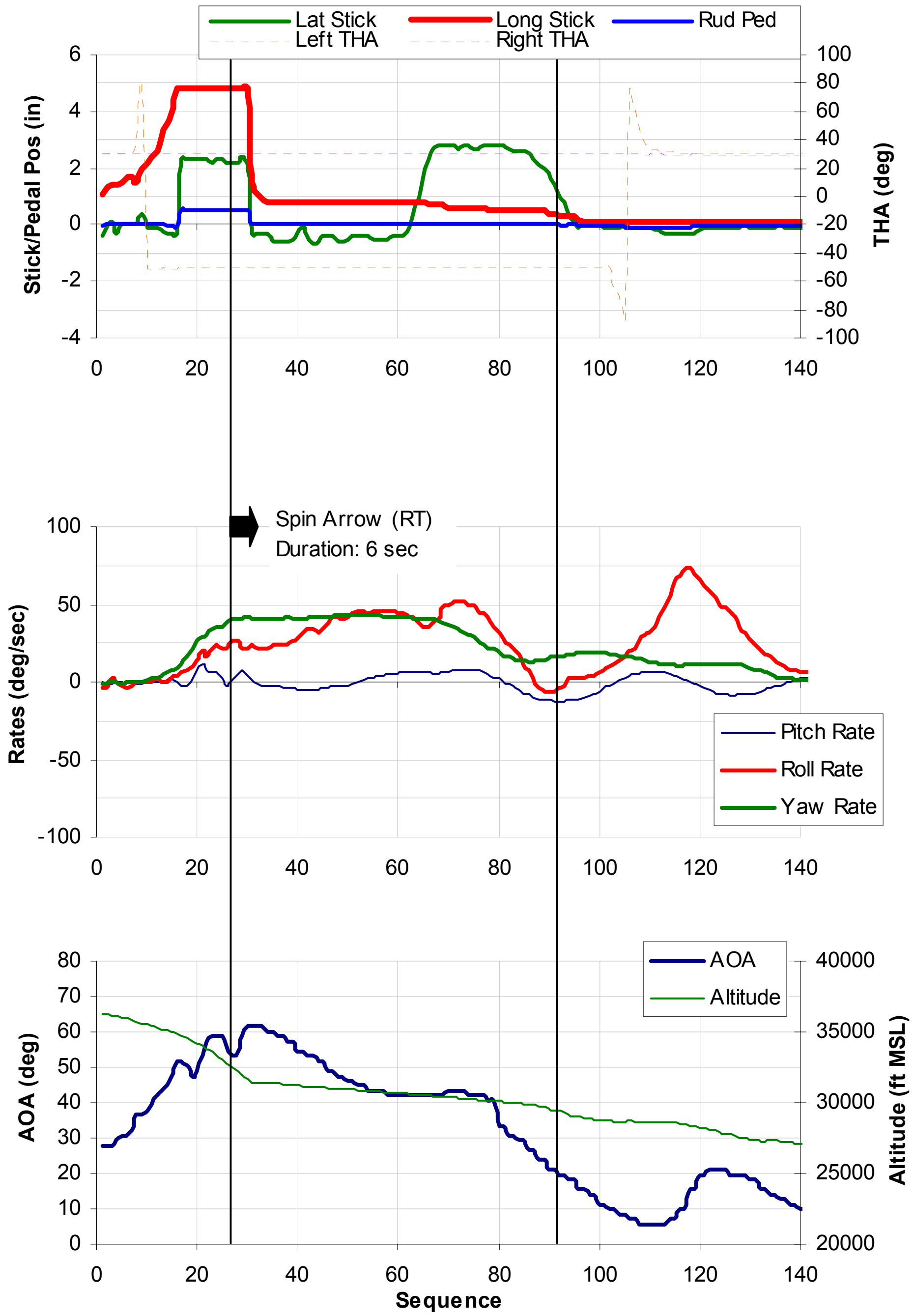
Entry Technique: Full Pirouette for 1.5 Turns
Recovery Technique: Neutralize Controls



Note: 1. Time scale is different prior to and after the spin arrow.
2. 10 sequences per second while the spin arrow is displayed.

Figure IV-4. ASRM Spin Procedure Development (Spin 5, July 16, 2003)

Entry Technique: Full Pirouette for 1.5 Turns
Recovery Technique: Neutralize Controls / Lat Stick with Arrow



Note: 1. Time scale is different prior to and after the spin arrow.
2. 10 sequences per second while the spin arrow is displayed.

Figure IV-5. ASRM Spin Procedure Development (Spin 6, July 16, 2003)

CHAPTER V
FLIGHT DATA ANALYSIS

The F/A-18 Hornet has become extremely stable, laterally and directionally, with FCC OFP v10.7. Initial flight testing of v10.7 showed that the spin entry technique used with v10.5.1 would not generate enough yaw rate. Appendix C, card 9 describes the spin entry procedure for v10.5.1. Spin entry with v10.7 would use the same entry procedure up to the full aft stick application. However, because of the improvements made in v10.7, the subsequent spin entry procedures would have to change. For example, unlike v10.5.1, full aft stick with v10.7 results in steady wings level flight with 15 to 20 degrees nose up, 55 to 60 degree angle of attack, and approximately 3,500 feet per minute altitude loss. With v10.7, moving the stick laterally for one inch with full aft stick resulted in no lateral or directional movement of the aircraft. With v10.7, lateral stick input at high angles of attack primarily deflects the rudder and differential stabilators to initially yaw then roll the aircraft in the direction of the input. Unlike v10.5.1, one inch of lateral stick input with v10.7 does not displace the aircraft due to the sideslip and sideslip rate feedback fighting to keep the aircraft stable. In fact, lateral and directional maneuverability with full aft stick is very sluggish but controllable and it takes full lateral control input to move the aircraft.

The test team, understanding the basics of v10.7, suggested early in the development program that the only way to generate enough yaw rate to enter a spin in ASRM was to use the pirouette enhance logic of v10.7. Just to be certain, spin entry attempts with single axis input with full aft stick were conducted. These were full aft stick with full rudder only and full aft stick with full lateral stick only. Neither produced enough yaw rate to enter a sustained spin repeatedly.

MIL/Idle or MAX/Idle throttle split?

With v10.5.1, MIL/Idle throttle split created enough asymmetric thrust to sustain the spin once it was entered. However, with v10.7, the MIL/Idle throttle split did not help generate enough yaw rate to display the spin arrows. Table IV-1 and IV-2 show comparison of MIL/Idle and MAX/Idle throttle split. Direct comparison of the throttle split between Records 1-26 and 1-27 from February 11, 2003 shows that maximum yaw rate and maximum lagged yaw rate are less with MIL/Idle throttle split. With the pirouette inputs held for just one turn, MIL/Idle split resulted in 40 degrees per second maximum yaw rate and 12 degrees per second maximum lagged yaw rate. The same pirouette inputs with MAX/Idle split resulted in 48 degrees per second maximum yaw rate and 15 degrees per second maximum lagged yaw rate.

Another direct comparison of the throttle split was made on February 12, 2003 and the results are shown in Table IV-2. With the pirouette inputs held for 1.5 turns, MIL/Idle split resulted in 43 degrees per second maximum yaw rate and 16.9 degrees per second maximum lagged yaw rate, just shy of the required 17 degrees per second lagged yaw rate for display of spin arrows. Spin with the MAX/Idle split after 1.5 turns of pirouette inputs resulted in display of spin arrows.

How long to hold the pirouette inputs?

The goal of the spin demonstration development was to develop a simple repeatable procedure to properly demonstrate the spin characteristics of the F/A-18 Hornet. For a pilot in the cockpit looking outside the cockpit or through the heads-up-display (HUD), it is easier to count the turns than to look at the clock and count the seconds. Previous testing with the MSRM had shown that pirouette inputs held to less than one turn did not generate enough yaw rate. Record 1-27 spin, with pirouette inputs held for just one turn, resulted in enough yaw rate but not enough lagged yaw rate to trigger the spin arrows. Subsequent spin attempts with MAX/Idle throttle split and pirouette inputs held for 1.5 turns resulted in repeatable spin arrows. Table IV-3 results show repeatable maximum yaw rate averaging approximately 50 degrees/second when the pirouette control inputs are held for 1.5 turns. Additional test conducted on July 16, 2003 also confirms the spin repeatability of holding the pirouette control inputs for 1.5 turns. These results are shown on Figures IV-2 to IV-5 and the average altitude loss was approximately 3,840 feet.

Another spin entry technique that was explored was holding the pirouette inputs until spin arrows appear. The example of this is shown in Figure IV-1. After approximately 4,700 feet of altitude loss, spin arrows appeared while holding full pirouette input controls. This occurred approximately at sequence 30. Pilot neutralized the control inputs as soon as he saw the spin arrows appear. However, since the control stick was already in the direction of the spin arrows when they appeared, the spin recovery mode engaged immediately and yaw rate started to decrease after one second, around sequence 40. With the controls completely neutralized at sequence 60 (3 seconds after the appearance of the spin arrows), Automatic Low-Rate Spin Prevention control law, along with the control system driving the aircraft below 22 degrees angle of attack, worked to automatically decrease the yaw rate. Initial spike in roll rate (around sequence 40) is contributed to the lateral stick input that was held in for the pirouette control inputs when the spin arrows appeared. This lateral stick input for the pirouette inputs converted to pure full roll control input as soon as the spin arrows came up. Initial decrease in roll rate (around sequence 55) came as the control stick was neutralized. As the angle of attack and yaw rate decreased, residual motion and inertial coupling took over and converted the aircraft motion to another spike in roll rate. However, as the angle of attack decreased further and the aircraft pitch attitude continued lower, the inertial coupling limiter kicked in and the roll rate decreased to almost zero.

Comparison of Recovery Methods

Recovery from spin demonstration with v10.5.1 involved holding the full aft stick while applying anti-spin lateral control stick input towards the direction of spin arrows. This recovery procedure was different than the published and authorized NATOPS spin recovery procedure. This was due to the fact that a F/A-18 with v10.5.1 would not intentionally spin without the control stick at full aft. With v10.5.1, intentional spin could only be maintained with full aft stick and the aircraft would automatically recover from the spin if the stick were allowed to come off the aft stop.

During the v10.7 evaluation, the test pilots used NATOPS spin recovery procedure to recover from the spin once spin arrows were displayed. The NATOPS spin recovery procedure directs the pilot to apply lateral anti-spin control input in the direction of the spin arrows while maintaining neutral longitudinal stick and neutral rudder. Test pilots generally felt that the spin arrows were displayed long enough to meet the spin demonstration training objectives and recovery was immediate with NATOPS spin recovery procedure. In order to maximize the training environment while in a spin, further tests were conducted to compare different recovery techniques. Figures IV-1 to IV-5 display the results of these flights and the results are summarized in Table V-1.

Figure IV-1 shows the recovery results from neutralizing all control inputs and pulling the throttle back to idle. Although the spin arrows are displayed for six seconds, note that the recovery roll rate is oscillatory. As previously mentioned, the oscillatory roll rate is a consequence of the prolonged pirouette control inputs that were held until the display of the spin arrows. As for the throttles, previous v10.7 evaluation had shown that the throttle splits have little effect on the recovery from a spin. In other words, pulling back both throttles to idle does not necessarily aid in recovering from a spin. This is confirmed by Figure IV-4, where the aircraft recovered from a spin with greater then 50 degrees per second maximum yaw rate without any anti-spin control input while throttles were split MAX/Idle.

Loss of altitude during spin recovery is also an issue for the spin demonstration. Once the spin arrows are displayed and anti-spin control input is made, desired result would be to lose as little altitude as possible until the spin arrows are removed. Figure IV-1 spin had the least altitude loss with spin arrows displayed. As previously mentioned, this was due to the fact that the anti-spin control input was already in place when the spin arrows appeared. As we can see from Table V-1, spin recovery using the lateral stick input resulted in the least altitude loss with or without the full aft stick input. Anti-spin lateral input with full aft stick (Figure IV-3) resulted in the least altitude loss while the spin arrows were displayed. However, note that the lateral anti-spin input was applied one second longer than Figure IV-5. Also note that although the anti-spin inputs were both applied when the yaw rate was 41 degrees per second, Figure IV-5 spin recovered in less time.

It is interesting to note that the aircraft recovers from the spin without any anti-spin control input but takes longer to recover as seen in Figures IV-2 and IV-4. As previously mentioned, automatic recovery from spin is enabled by aircraft seeking less than 22 degrees angle of attack without any aft stick input and by the Automatic Low-Rate Spin Prevention logic.

Table V-1. Comparison of Flight Data Results from July 16, 2003

Figure	IV-1 Spin 1	IV-2 Spin 2	IV-3 Spin 3	IV-4 Spin 5	IV-5 Spin 6
Entry Technique (Pirouette Input Duration)	Held until Arrows	1.5 turns	1.5 turns	1.5 turns	1.5 turns
Altitude Loss until Spin Arrow Display	4,736 ft	4,032 ft	3,936 ft	3,840 ft	3,552 ft
Max Yaw Rate	60 deg/sec	52 deg/sec	58 deg/sec	59 deg/sec	43 deg/sec
Spin Arrow Display Duration	6 seconds	14 seconds	6 seconds	10 seconds	6 seconds
Altitude Loss with Spin Arrow	2,272 ft	4,384 ft	2,656 ft	3,744 ft	3,168 ft
Ave. Yaw Rate during Arrows	31.3 deg/sec	28.2 deg/sec	35.2 deg/sec	41.7 deg/sec	35.0 deg/sec
Recovery Technique	Neutralize Controls Synch Throttles	Hold FAS, Lat Stick & Rudder Neut.	Hold FAS, Lat Stick w/ Arrow	Neutralize Controls	Neutralize Controls, Lat Stick w/ Arrow
Yaw Rate at Anti-Spin Input	N/A	N/A	41 deg/sec	N/A	41 deg/sec
Anti-Spin Input to Recovery	N/A	N/A	3 seconds	N/A	2 seconds
Total Altitude Required to Demonstrate the Spin	7,008 ft	8,416 ft	6,592 ft	7,584 ft	6,720 ft

CHAPTER VI
CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this evaluation was to evaluate the capability to demonstrate the F/A-18 Hornet spin departure characteristics with v10.7. The ability to spin the F/A-18 without entering any degraded flight control mode was demonstrated during the evaluation. This was important since it eliminated the need for any complicated cockpit switch movement or system configuration change, thus keeping the set up for the spin demonstration simple.

MAX/Idle Throttle Split

Although only four spins were conducted to directly compare MIL/Idle and MAX/Idle throttle splits, results were clear. In both cases, MAX/Idle split resulted in greater maximum yaw rate and greater maximum lagged yaw rate. No further testing of the throttle split differences was required since the fuel expended with MAX/Idle split was not considered significant to warrant further evaluation. Clearly MAX/Idle split was superior in achieving the training objective of demonstrating the spin characteristics of the F/A-18.

Full Pirouette Control Inputs for 1.5 Turns

The throttle splits alone would not spin the F/A-18. As a matter of fact, the throttle splits only accounted for a very little portion of the overall capability to spin the F/A-18. In order to spin the F/A-18, pro-spin control inputs must be applied. Flight test evaluated the pirouette inputs to generate the yaw rate to spin the aircraft. The results showed that the pirouette inputs would have to be applied for greater than 1.5 turns to generate enough yaw rate to display the spin arrows. Holding the pirouette control inputs until the spin arrows were displayed would have made the procedure simpler since the pilot would not have to count the number of spin turns. Although this technique generated higher yaw rate, it was abandoned for a few reasons: greater number of turns, greater time, and greater loss of altitude required to display the spin arrows and immediate spin recovery mode engagement when the spin arrows appeared.

Pirouette control inputs held for 1.5 turns seemed to work the best. First, it was easier to count the turns in half turn increment and most pilots preferred to count them half turn (180 degrees of yaw) at a time. Although not entirely exact in number of degrees, any approximate completion of 1.5 turns seemed to generate enough yaw rate. Once the pro-spin lateral stick and rudder inputs were removed the spin arrows would display repeatedly. Average maximum yaw rate was approximately 50 degrees per second and average altitude loss until the spin arrows appeared was no greater than 4,000 feet. Since the purpose of the spin demonstration was not to disorient the pilot, 50 degrees per second was considered satisfactory for instructional purposes.

Neutralize the Controls then NATOPS Spin Recovery

For instructional purposes, three seconds or more in a sustained spin with the spin arrows displayed is desired. This gives the pilot enough time to assess the spin arrow, altitude, AOA, airspeed, and the yaw rate before applying anti-spin control input. It is also desirable to recover from the spin with minimum altitude loss once the anti-spin control input is applied. Figures IV-2 and IV-4 showed that the spin could be sustained once pro-spin control inputs are removed. Holding full aft stick with neutral lateral stick and rudder (Figure IV-2) proved to prolong the spin the longest (14 seconds). However, neutralizing all control inputs (Figure IV-4) resulted in long enough spin arrow flight environment (10 seconds) to assess the spin characteristics of the F/A-18. Although neutralizing the lateral stick and rudder prolonged the spin and allowed the pilot to experience the spin characteristics longer, it was not an effective recovery technique. It is comforting to know that the aircraft would recover from a spin without applying any anti-spin control input, but the training objective is to have the pilot actively recover from a sustained spin. Therefore, applying anti-spin control input to recover from the spin would have to be a part of the spin demonstration.

Two anti-spin control input recoveries were evaluated: lateral stick into the direction of the spin arrows with full aft stick (Figure IV-3) and lateral stick into the direction of the spin arrows with neutral longitudinal stick (Figure IV-5). Table V-1 is used to compare the two recovery techniques. Although the altitude loss with spin arrows is less with full aft stick, it took one second longer to recover once the anti-spin control input was applied at the same yaw rate (41 degrees per second). The total altitude required to demonstrate the spin for the two different recoveries were about the same. For the pilot performing the procedures, it was easier to neutralize or release any control input than to hold full aft stick throughout the maneuver. It is also ideal to begin the spin demonstration recovery from neutral control stick and rudder since the NATOPS spin recovery procedure starts from neutral control stick and rudder position. NATOPS spin recovery procedure states if the spin arrow is present, lateral stick should be applied in the direction of the spin arrow.[3] Once the yaw rate is stopped, lateral stick should be neutralized smoothly. Using the exact NATOPS spin recovery procedure will allow the pilot to build confidence in the published NATOPS spin recovery procedure. Unlike v10.5.1, spin with v10.7 does not require holding full aft stick to sustain the spin. Therefore, once the spin arrows are displayed control inputs should be neutralized. Following a quick evaluation of the F/A-18 spin characteristics for approximately three seconds, then the NATOPS spin recovery procedures should be used to recover from the spin.

Recommended Procedure for v10.7 Spin Demonstration

In conclusion, the spin demonstration procedure with v10.7 should use the pirouette control inputs for 1.5 turns to generate the yaw rate for spin. Then the control inputs should be neutralized to bring up the spin arrows. Once a brief assessment of the spin characteristics are noted, the NATOPS spin recovery procedure should be used to recover from the spin. The following spin demonstration procedure is recommended for v10.7 Automatic Spin Recovery Mode Demonstration:

1) Stabilize wings level, 150 KCAS and 35,000 feet.
2) Slowly reduce both throttles to IDLE.
3) Set 15 to 20 degree pitch attitude and hold.
4) When AOA tone is present (approximately 35 AOA) smoothly apply full aft stick while noting heading or ground reference.
5) Firmly hold full aft stick and smoothly increase thrust on left/right engine to MAX with opposite engine at IDLE. Simultaneously apply full lateral stick and rudder pedal (full pirouette control inputs) into the direction of the throttle at IDLE.
6) Hold the control inputs for 1.5 turns while counting every half turn looking outside the cockpit.
7) After 1.5 turns, neutralize control stick and rudder pedal inputs - release the control stick and take feet off the rudders.
8) Automatic Spin Mode logic should activate within 1/4 turn.
9) Note the spin arrows, altitude, AOA, airspeed, and yaw rate.
10) Proceed with NATOPS spin recovery procedure: apply lateral stick in the direction of the spin arrows.
11) Continue to look outside the cockpit.
12) When yaw rate ceases, neutralize the lateral stick.
13) Note when the spin arrows disappear.
14) Bring both throttles to IDLE and complete NATOPS Out-of-Control Recovery procedures by waiting for AOA/yaw tones to be removed, side-forces to be subsided, and aircraft to increase through 180 KCAS prior to recovering from the nose low attitude.

Due to safety, a spin should not be intentionally prolonged and spin recovery should be initiated so that the aircraft recovers by 25,000 ft. Also note that spin characteristics evaluation once the spin arrows are displayed should not be prolonged since the aircraft will eventually recover from the spin without any pilot input. This defeats the purpose of the spin demonstration training. However, automatic recovery of the spin can be demonstrated to the pilot in training as an option. This will demonstrate that if the pilot is unsure of what to do, the aircraft will recover on its own with enough altitude to spare. Therefore, if the pilot is unsure of what to do, he/she should not move the control stick or rudders. The complete recommended v10.7 departure demonstration flight syllabus cards are shown in Appendix D.

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BIBLIOGRAPHY

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APPENDICES

Appendix A
AIRFRAME DESCRIPTION

The F/A-18 Hornet is a fighter/attack aircraft built by McDonnell Douglas Aerospace. It is powered by two General Electric F404-GE-400 or F404-GE-402 (enhanced performance) turbofan engines with afterburner. The aircraft features a variable camber mid-wing with leading edge extensions (LEX) mounted on each side of the fuselage from the wing roots to just forward of the windshield. The twin vertical stabilizers are angled outboard 20 degrees from the vertical. The wings have hydraulically actuated leading edge and trailing edge flaps and ailerons. The twin rudders and differential stabilators are also hydraulically actuated. The speed brake is mounted on the topside of the aft fuselage between the vertical stabilizers. The pressurized cockpit is enclosed by an electrically operated clamshell canopy. An aircraft mounted auxiliary power unit (APU) is used to start the engines. On the ground, the APU may be used to supply air conditioning or electrical and hydraulic power to the aircraft systems.

Figure A-1. F/A-18D Hornet of VMFA(AW)-242, the “Bats”

Appendix B
F/A-18A-D FLIGHT CONTROL SYSTEM OVERVIEW

The F/A-18 primary flight control system is a control augmentation system with fly-by-wire techniques. All control law computations are performed by four digital computers working in parallel. The digital computers are used in conjunction with redundant electrohydraulic servoactuators and analog sensors to provide two-fail-operate primary control capability. Digital open loop control of the stabilator, aileron and rudder surfaces is provided following three similar motion feedback sensor failures. Backup mechanical control of the stabilator surfaces is available in the event of three digital processor failures or total electrical failure. Backup open loop analog control of the aileron and rudder surfaces is also available if the digital processors fail. Locations of the flight control system components are shown in Figure B–1. Figure B–2 is a functional diagram of the flight control system.

The control augmentation system uses gain scheduling, cross axis interconnects (e.g., rolling surface to rudder) and closed loop control of aircraft response to enhance flying qualities, protect the aircraft from overstress, actively control structural mode oscillations, and augment basic airframe stability. AOA and air data parameters are used for gain scheduling the control system to accommodate varying flight conditions. Fixed gain values provide safe control upon failure of AOA or air data sensing. Out-of-control flight (spin) is automatically sensed and the control laws are reconfigured to facilitate recovery.

Digital direct electrical link control laws provide open loop control if the motion feedback sensors fail. The direct electrical link modes are gain scheduled if air data and angle of attack have not failed. Otherwise, they operate with fixed gains.

Automatic flight control modes using signals from other aircraft systems provide pilot relief (auto-pilot) and coupled data link guidance modes. The pilot relief functions include heading hold, heading select, coupled steering, pitch and roll attitude hold, and barometric and radar altitude hold. The coupled data link modes are automatic carrier landing, instrument landing system, vector, and precision course direction. Traffic control and coarse course direction are heading command submodes of automatic carrier landing and precision course direction, respectively.

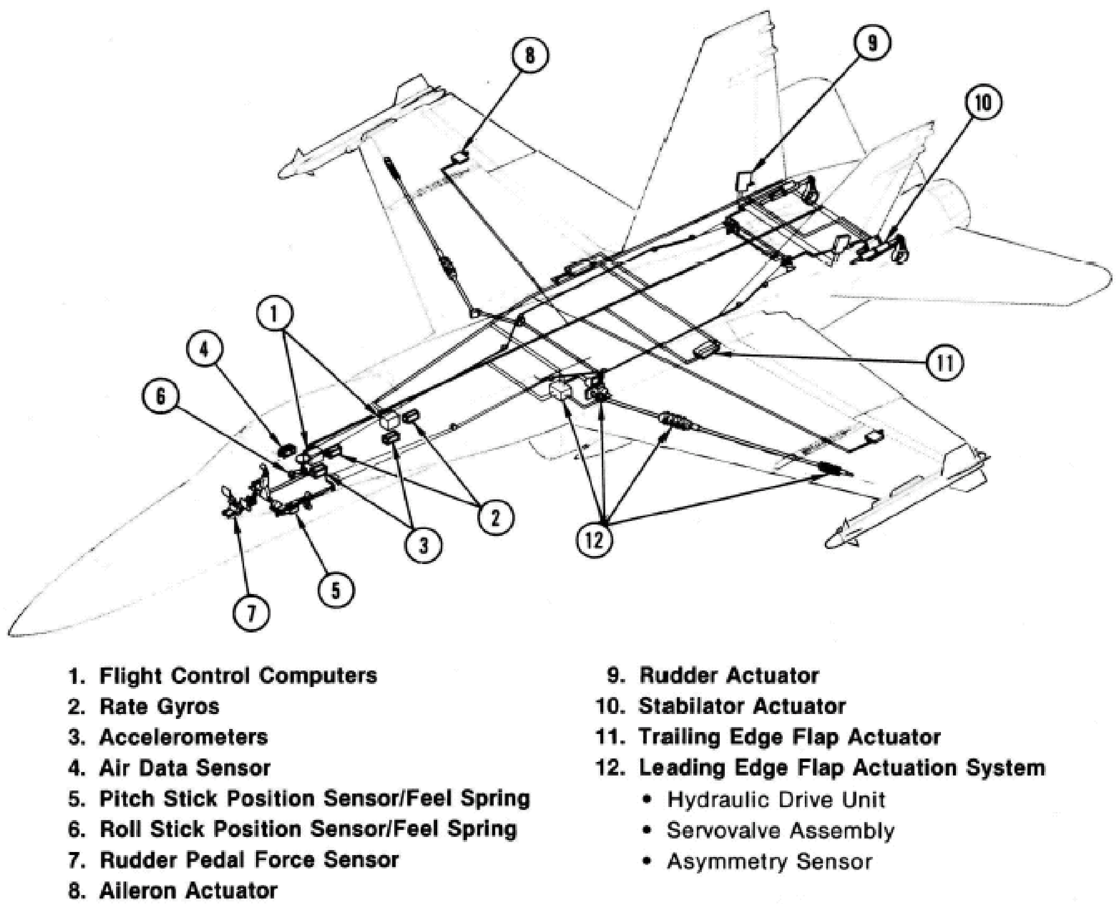


Figure B-1. F/A-18 Flight Control System

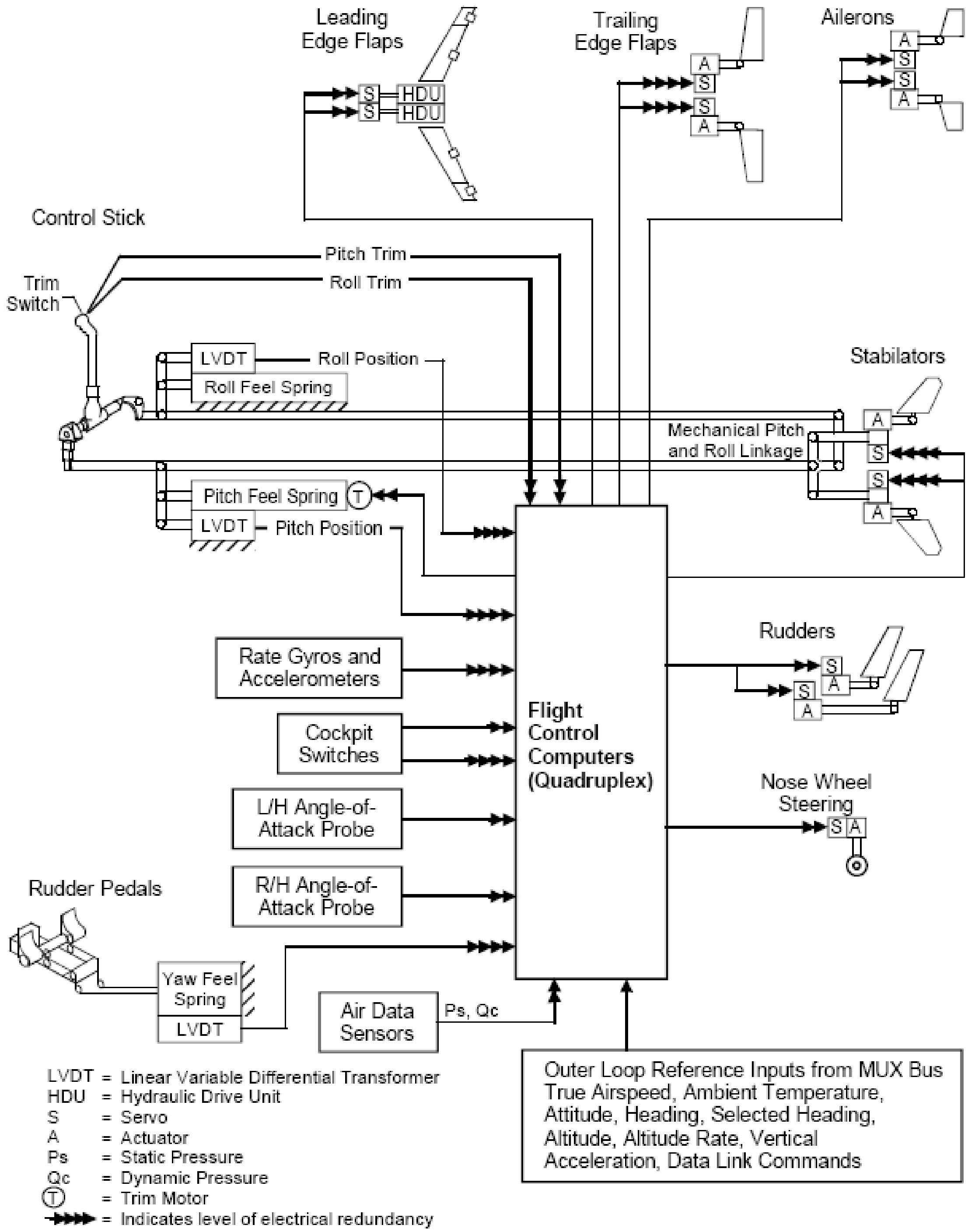


Figure B-2. Flight Control System Functional Diagram

Vector is also a heading command mode while automatic carrier landing, instrument landing system, and precision course direction provide both longitudinal and lateral control using commands from shipboard or ground based radar guidance systems, respectively. An autothrottle system is incorporated into the flight control system to control air speed. During carrier landing, the autothrottle functions as an approach power compensator to maintain the optimum approach AOA. For up and away flight conditions, the autothrottle functions as a velocity hold mode. Nosewheel steering control laws and failure logic are incorporated in the flight control system and provide two nosewheel steering authority ranges for high and low taxi speeds.

The flight control system includes a built-in-test system with two basic modes: periodic and initiated. Periodic built-in-test provides fault detection and isolation whenever the control laws are being computed by examining the status of the redundancy management logic. Initiated built-in test operates only on the ground and provides more comprehensive fault detection and isolation.

Control Surface Configuration

There are ten primary flight control surfaces on the F/A-18 each of which is part of a left/right pair: stabilators, rudders, ailerons, leading edge flaps and trailing edge flaps. Longitudinal control uses symmetric deflection of the stabilators, leading and trailing edge flaps and, during the power approach configuration, symmetric droop of the ailerons and toe-in of the rudders. Lateral-directional control uses differential deflection of the stabilators, ailerons and leading and trailing edge flaps and synchronous rudder deflections. The ranges of control surface deflection are shown in Table B–1.

The control system mode logic and gain schedules can limit the surface commands to less than maximum deflection at some flight conditions.

Table B-1. Control Surface Deflection Ranges

Control Surface	Deflection Range
Stabilators	24 deg TEU to 10.5 deg TED
Ailerons	25 deg TEU to 45* deg TED
Rudders	30 deg TEL to 30 deg TER
Trailing Edge Flaps (TEF)	8 deg TEU to 45 deg TED
Leading Edge Flaps	3 deg LEU to 34 deg LED

TEU = Trailing Edge Up　　TER = Trailing Edge Right
TED = Trailing Edge Down　　LEU = Leading Edge Up
TEL = Trailing Edge Left　　LED = Leading Edge Down
* Software limited to 42 deg TED

Major System Components

The major components of the flight control system include the Flight Control Electronic Set, electrohydraulic servoactuators, and the mechanical control system. Figure B–1 shows the locations of these components. These components are integrated with other aircraft systems to provide the total flight control capability. The other aircraft systems include the hydraulic and electrical systems, cockpit controls and displays, Mission Computer, Stores Management Set, Air Data Computer, Inertial Navigation Set, Data Link Receiver, Radar Altimeter, angle of attack sensors, and the pitot-static system.

The Flight Control Electronic Set is comprised of the following Weapon Replaceable Assemblies:

- 2 Flight Control Computers each containing two channels of digital and analog signal processing functions
- 2 Rate Sensor Assemblies each containing two pitch, two roll, and two yaw angular rate gyros
- 2 Accelerometer Sensor Assemblies each containing two normal and two lateral linear accelerometers
- 1 Air Data Sensor containing two static and two impact pressure sensors
- 1 Flight Control Panel containing the system reset, takeoff trim and gain override switches and the rudder trim control
- 1 (2 for two-place aircraft) Rudder Pedal Sensor Assembly containing the rudder pedal feel spring and four transducers which measure the feel spring's displacement and hence pedal force

Each flight control surface is driven by a fly-by-wire electrohydraulic servoactuator, which is controlled by the Flight Control Computers. In addition, the stabilator servoactuators respond to the mechanical control system commands if fly-by-wire control to these surfaces has failed. The Flight Control Computers also control the nosewheel steering actuator, a servoactuator on each engine and automatic retraction of the speed brake actuator in the Power Approach flight phase.

The mechanical control system includes the cockpit control stick, longitudinal and lateral feel springs, longitudinal trim actuator, linkage and cables between the control stick and stabilator actuators, and an electromechanical ratio changer which adjusts the stick-to-stabilator gearing as a function of the flap switch position. Quadruplex position transducers are mounted in parallel with longitudinal and lateral feel springs to provide the Flight Control Computers with electrical signals proportional to the control stick deflections.

Redundancy Level

The functional redundancy of the closed loop control augmentation system, exclusive of angle of attack and air data scheduling, is quadruplex. Failure monitoring and voting of the input sensors and servoactuators provides two-fail-operate performance for augmented motion feedback control. Although certain dual failure combinations may result in loss of control of a single aileron, rudder, or leading edge flap, the corresponding surface on the opposite side continues to provide control for the affected function. Depending upon the type of third failure, the resultant configuration may be a combination of augmented, motion feedback, and/or unaugmented open loop control. The unaugmented configurations are: pitch and roll mechanical stabilator control; digital direct electrical link control of the stabilators, ailerons and rudders; and analog direct electrical link control of the ailerons and rudders.

AOA sensing uses dual airstream vanes each of which drive two transducers that provide a total of four electrical signals to the Flight Control Computers. Failure monitoring and voting results in alternate angle of attack estimates being used in the flight control laws if two electrical failures occur on the same side. This will degrade control augmentation performance and require the flight envelope to be limited. No degradation occurs for a single electrical failure or two such failures on opposite sides.

The Air Data Sensor is the only source of information for air data scheduling of the flaps and control augmentation gains. The Air Data Sensor is dual channel and each channel is connected to one of the aircraft pitot-static probes located beneath the AOA vanes. The air data redundancy management uses inline monitoring, which provides single fail operate performance for either pitot-static probe or transducer failures. If a single air data sensor transducer failure is detected the remaining air data sensor transducer is used for the control laws providing single fail operate performance. A second Air Data Sensor failure inhibits air data commands and flap scheduling with resulting control augmentation degradation and flight envelope restrictions.

The servoactuators have both electrical and hydraulic redundancy characteristics, which are summarized in Table B–2. The F/A-18 flight control system uses aircraft motion feedbacks in a control-by-wire and full authority Control Augmentation System (CAS) mechanization. The longitudinal control system uses a blend of air data scheduled pitch rate, normal acceleration, and AOA feedback. Pitch rate and normal acceleration feedbacks improve aircraft stability and flight path (normal acceleration) control in the mid-to-high dynamic pressure flight regime. Air data scheduled pitch rate feedback also provides good tracking capability and increased stick-force-per-g cues in the low-to-mid dynamic pressure flight regime. AOA feedback provides increasing stick force cues for high AOA maneuvering. Trailing edge and full span leading edge maneuvering flaps are scheduled with AOA and air data to optimize performance characteristics, to improve the high AOA lateral-directional aerodynamic characteristics, and provide load alleviation.

Table B-2. Actuator Redundancy Characteristics

Actuator	Electrical Redundancy	Hydromechanical Redundancy	Hydraulic Supply Pressure Backup
Stabilator	Quad 2-Fail Operate Fail to Mechanical	Dual Fail-Operate Fail to Flutter Damper Mode	One system only
Trailing Edge Flap	Quad 2-Fail Operate Fail to Neutral	Dual Fail-Operate Fail to Neutral	None
Leading Edge Flap	Dual Fail-Operate Fail to Off and Hold Last Positions	Single Fail to Off and Hold Last Position	Yes
Aileron	Dual Fail-Operate Fail to Flutter Damper Mode	Single Fail to Flutter Damper Mode	Yes
Rudder	Dual Fail-Operate Fail to Flutter Damper Mode	Single Fail to Flutter Damper Mode	Yes
Nosewheel Steering	Dual Fail-Safe to Shimmy Damper Mode	Single Fail to Shimmy Damper Mode	None
Autothrottle	Single Fail-Safe to Off	Single Fail-Safe to Off	None

The lateral control system uses air data scheduled roll rate feedback to provide increased roll damping at low-to-mid dynamic pressure. The roll control surfaces include ailerons, stabilators, and leading and trailing edge flaps. Aileron control surface command gain is reduced with increasing dynamic pressure in the high dynamic pressure flight regime to alleviate roll reversals caused by flexibility effects. Differential stabilator surface command gain is reduced in the high dynamic pressure region to avoid hinge moment limiting. Differential stabilator surface command gain is also reduced with increasing load factor for bending moment alleviation. Aileron and differential stabilator surface command gain is reduced with increasing angle of attack to improve roll control and minimize adverse sideslip. The differential trailing edge flap surface command gain is reduced in the high dynamic pressure region to avoid hinge moment limiting and excessive vertical tail loads. The differential trailing edge flap gain is scheduled to zero above 10 deg angle of attack, where differential flaps are not required for adequate roll performance. Differential leading edge flaps are gain scheduled with Mach, altitude, and load factor to provide roll control in the low-to-mid altitude transonic speed regime. The differential leading edge and trailing edge flaps are not used in Power Approach.

The directional control system uses cancelled stability axis yaw rate feedback for increased directional damping and lateral acceleration feedback for increased directional stability. In Power Approach, a full time beta-dot (rate of change of sideslip) estimator is employed to increase the directional damping and stability for the carrier landing phase.

A rolling surface-to-rudder interconnect (scheduled with angle of attack and air data) is used for roll coordination. A ruder pedal-to-rolling surface interconnect is employed to optimize rudder pedal roll characteristics in the Auto Flap Up mode and to limit maximum steady heading sideslips in Power Approach.

Appendix C
10.5.1 DEPARTURE TRAINING FLIGHT CARDS

F/A-18 Departure Training Flight
Standardization Instructor Cards

Event No: ______ A/C: ________ Date: _________

Takeoff time________ Landing time ________

FCS Load: 10.5.1	Loading: **Total Fuel = 11.9**
Area:	STATION 1/9 **CLEAN**
	STATION 2/8 **CLEAN**
Hot Pit/Switch:	STATION 3/7 **PYLONS**
	STATION 4/6 **CLEAN**
	STATION 5 **Pyl+Tank**

LIMITS: **Departures will be only with C.G. at or forward of 23.5%**
AOA limit -6 to 25° with cg 23.5-28% (centerline)
FE AOA limit -6 to 20° 0.7 M to 0.8 M

	GEAR UP	GEAR DN
TAKEOFF GW / CG	/	/

BINGO:________________________

CALL SIGNS: ____________

UHF FREQ: ____________

Pilots:____________________

24 Jun '02 1

Admin

FLIGHT CLEARANCE PERMITS: *(For B & D only)*

- **INTENTIONAL DEPARTURES**
  - **C/L TANK EMPTY FOR ALL DEPARTURES**
  - **CG MUST BE AT OR FWD OF 23.5% MAC FOR DEPARTURES OR HIGH YAW RATE MANEUVERING**
  - **MIN DEPARTURE ENTRY ALTITUDE = 30,000 FT AGL**
  - **MAX MACH FOR ENTRY = 0.7 M**
- **TAILSLIDES (Incl. 15 sec at 0g)**
- **YAW RATE > 25 deg/sec only W / FCS IN CAS OR ASRM**
- **MANUAL SRM < 250 KCAS**
  - **SPIN SWITCH TO NORM AT AOA OR YAW RATE TONE** *(Even if momentary)*

2

MAINTENANCE CONTROL PROCEDURES

Review ADB for:
- *Any FCS issues*
- *Any recent FCF*
- *Recent Flight Control Surface Rigging*
- *Radome Patches*

PRE-FLIGHT PROCEDURES

Observe Aircraft for:
- *Radome –*
  - *1st 8 inches and predominantly lower ½*
  - *Rain boot / seal smooth*
  - *Rub with hand to determine imperfections*
- *LEF Tape*
- *Freeplay in LEF (+/-)*
- *Both wingfold covers on (taco shells)*

POST-START PROCEDURES

SPIN RECOVERY MODE CHECK *(After IBIT)*

3-1. Flaps – Auto*(F/A-18D: FCS page on MPCD)*
3-2. Spin Recovery Switch – RCVY
3-3. Check DDI's – SPIN MODE ENGAGED
3-4. Flaps – LEF Down 34 deg / TEF up 0 deg
3-5. Spin Recovery Switch - NORM

TRIM CHECK

3-6. Press T/O trim button
3-7. Verify aileron and rudder neutral, stabilator 12 deg nose up and T/O TRIM advisory on (*back-up indication of 10.5.1 PROM)*
3-8. BIT – CONFIG page
F/A-18B: FCCA/B **= 117**
F/A-18D: FCCA/B **= *91C-004***

3

KNOCK-IT-OFF / ABORT CRITERIA

GROUND

- Form F inaccuracies
- Failure of SRM checks
- Incorrect flight control PROM
- Gross Abnormalities with flight controls
- No HUD tape
- MU Full

AIRBORNE

- Failure of RIG check
- Failure of Radome check
- Engine stalls
- MMP 925
  Negative g overstress
- FCS X's or anomalies
  Expected Cautions during Dynamic Maneuvers:
  FC AIR DAT
  V VEL
- Dive recovery initiated <20,000 ft AGL
  **** Do not fly aircraft for Departure Demo until resolution obtained from Model Manager***
  [Call Model Manager, Save HUD tapes, have Maint save ECAMS data to include Code 40, 42, & 46 data (Warnings/Cautions and PASS 1,2,&3 data) in .ADF format]

4

PRE-MANEUVER CHECKS

PRE-FIRST MANEUVER CHECKLIST

- **UHF / ICS:Hot Mike - Check**
- **Altimeter - Local**
- **Loose Items / Harness / Visor / FOD Check (*Bring minimum to cockpit, cinch lap belts*)**
- **Master Mode - NAV**
- **HUD SYM – NORM**

PRE-MANEUVER CHECKLIST

- **Fuel Balance - Check**
- **CG - Check**
- **Area clear - Check**

5

AIRBORNE RIG CHECK

Stan *- Y,* ***IUT*** *– As Req,* ***Student*** *- N*

A/S – 200 KCAS **ALT –** 10,000 ft

Complete Pre-first Maneuver Checklist

6-1. Ensure all zeros on the first and third lines of memory inspect UNIT 14, ADDRESS 5016
- If not re-trim laterally until between 000000 & 000600 or 177200 & 177777

6-2. Wings level, 1g flight
Slow to 200 KCAS
Throttles - Ensure Symmetric

6-3. Observe ball
- Trim out ball at each A/S prior to release, if required

6-4. Release stick & record direction and time to 30° AOB / 6 sec
- 5 deg/sec max acceptable for Dep Demo

6-5. Accel to 300 - Repeat 5-4
- Probably Stabs, TEF, Ailerons

6-6. Accel to 400 - Repeat 5-4
- Probably TEF, Ailerons

6-7. Accel to 500 - Repeat 5-4
- Predominantly LEF

ABORT CRITERIA – Observed Roll Rates > 5 deg/sec

6

HIGH AOA STATIC STABILITY DEMO & RADOME CHECK

Stan *- Y,* ***IUT*** *– Y,* ***Student*** *- Y*

A/S – 250 KCAS **ALT –** 35,000 ft AGL

7-1. HUD VIDEO - ON
7-2. Lateral & Directional Trim - Centered Ball / No rates
7-3. Throttles - IDLE (Ensure Symmetric)
7-4. DDI - Monitor FCS
- LEF and TEF should lead AOA by 2-3 deg
- ~10 AOA first indication of buffet (Note: Remember this cue as 10 deg AOA is max desirable if you have an FCS failure)
- ~15 AOA LEF continue down while TEF begin coming up from 17
7-5. AOA - Sample lateral stick and rudder pedals at 15 deg, Throttles– MILITARY to reduce ROD
- AOA feedback blended in at 22 deg AOA
- At 22 AOA aft stick forces increase, auto trim ceases
30 deg Bank-to-bank rolls at 25 deg AOA
full lat stick only , then full rudder pedal only
- RSRI utilizing the rudder to counter adverse yaw – Lat Stick only: Rudders will lead turn then back off, Rudders only: Rudders will lead and not back off
Observe wing rock at 38-42 deg
- AOA Tone is not an A/C limit, expect to talk over tone
- Expected >20 deg WR, high as 60 deg observed
- Feet on the floor, hold neutral lateral stick, Note ROD
- Break AOA or dampen out wing rock with Rudder/Lateral Stick prior to going Radome Check
7-6. Radome Check – Check Altitude > 30,000 ft AGL.
Reset to 30-35 AOA and stabilize wings level. Note HDG. Throttles – IDLE, Increase smoothly to full aft stick (< 2 sec to FAS)
***Hold for 5 sec*, Note final HDG**
- Start above 30,000 ft AGL
- Observe yaw / roll rate
7-7. Recovery – Reduce AOA, Re-establish level flight
- Above 25,000 ft AGL

ABORT CRITERIA – Departure; Distinct Yaw Accel; Hdg Change > 60 in 5 sec at FAS; Spin Arrows

7

ACCELERATED FLIGHT RADOME CHECK

Stan *- Y,* ***IUT*** *– Y,* ***Student*** *- Y*

A/S – 200 KCAS **ALT –** 35,000 ft AGL
CG Calculate: _______

8-1. HUD VIDEO - ON

8-2. Throttles – IDLE
- Raise nose 5-10 deg

8-3. Accelerated entry to full aft stick, left 90° AOB
- 2 sec to Full Aft Stick
- Looking outside for nose slice due to radome
- Repeat as necessary

8-4. Hold full aft stick - 5 seconds
- Observe roll, yaw, pitch rate

8-5. Repeat - Right 90° AOB.
- Start 2nd one above 30,000 ft
- Observe LEF/TEF operation on FCS page
- Symmetrical extension and rate of extension
- HDU failure will be LEF not extending or ratcheting

Note: If abnormal tendencies, yaw rate tone, spin logic activates - NEUTRALIZE LONG STICK
- If continuing, you know what direction the aircraft has a propensity to go, plan your ASRM demo the same direction

ABORT CRITERIA – Departure; Distinct Yaw Accel; Spin Arrows; Tendency to roll upright with roll attitude change > 60 deg in 5 seconds; Yaw tone after AOA <35 during recovery

8

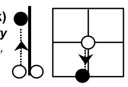
AUTOMATIC SPIN RECOVERY MODE DEMO

***Stan** - Y, **IUT** – Y, **Student** - Y*

A/S – 150 KCAS **ALT –** 35,000 ft AGL
CG Calculate: _______

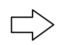
9-1. HUD VIDEO - ON
9-2. Slowly reduce both throttles to IDLE
9-3. Set 15 deg pitch attitude max and hold
- Use waterline symbol, fly aircraft until departure

9-4. At AOA tone onset- Increase thrust on one engine smoothly to MIL, smoothly apply aft stick,
Full Aft Stick when nose on horizon
(hold center to slight left/right lateral stick)
*- Avoid **nose high entry, may become oscillatory***
- Use two hands on aft stick otherwise during PSG,
Stall will break if stick moves off aft stop



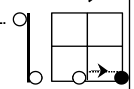
9-5. Identify/Observe Spin Motion
- Call out when outside cues identify a spin and
the lag when compared to when spin arrows appear

9-6. Check DDI - SPIN MODE
Note Spin Arrow appearance and direction

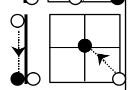


9-7. Maintain initial lateral stick input until yaw rate appears to stabilize, NLT 26,000 ft AGL.
- IP intervention at 25,000 ft AGL

9-8. Apply lateral stick with Spin Arrow
- Maintain Full Aft Stick, yaw rate may stop prior to
full lateral stick



9-9. Complete NATOPS Recovery
- When yaw rate stops – smoothly neutral
or expect opposite direction departure
- Expect spin arrows to lag – don't wait for arrows to be gone,
- Verbalize procedures (have them recite in brief), simultaneously
bring throttle to idle with lat/long stick input



9-10. Engines – Check

ABORT CRITERIA – Increasing oscillatory motion

9

LOW AOA/RUDDER DEPARTURE DEMONSTRATION

***Stan** - Y, **IUT** – Y, **Student** - Y*

A/S < 210 KCAS **ALT –** 35,000 ft AGL
CG Calculate: _______

Throttle friction - adjust for stiff throttles
- Lock harness

10-1. HUD VIDEO - ON

10-2. Throttles – MIL / Pull to 25° pitch attitude
- Don't hold, just touch 25 deg on waterline and start pushover

10-3. Pushover to ±5 deg AOA

10-4. Rudder Pedal - Abruptly apply full and hold

10-5. Longitudinal Stick - Maintain 0° to 3° AOA (±5° limit)

10-6. Lateral Stick – Minimize roll in direction of Rudder input
- Hold what you get, don't reverse roll otherwise possible neg. AOA depart
- '+' AOA depart – Roll & Yaw same direction
- '-' AOA depart – Roll & Yaw opposite, over the top depart, chance for neg g overstress (limit: –3.0 g)

10-7. Thrust - IDLE at first departure cue (vortex rumble, sideforce, etc)
- To increase engine surge margin, Expect RCP to have first cueing

10-8. Recovery - NATOPS OCF
- Verbalize procedures, grab towel racks, feet flat on floor

10-9. Engines - Check
- Negative g overstress MMP code – 925

CAUTION – Overstress possible if A/S > 210 KCAS

10

VERTICAL DEPARTURES

***Stan** - Y, **IUT** – Y, **Student** - Y*

A/S – 300 KCAS **ALT –** 30,000 ft AGL
CG Calculate: _______

11-1. HUD VIDEO - ON

11-2. Smoothly pull nose up to 70° to 90° Pitch reference waterline (1 % RULE)
- HUD symbology may float 40-70 deg NU, reference outside

11-3. Use forward stick to maintain nose position
- Less than 50 kts 'stir the pot' to show controls ineffective

11-4. Thrust - IDLE at departure
- Increase in surge margin

11-5. Recovery - NATOPS OCF
- Verbalize procedures, grab towel racks, feet flat on floor

11-6. Engines - Check

11-7. Repeat - Attempt to recover at 100 kt
- Don't give up trying to reach the horizon until the nose stops tracking, same as controls not responding, at that time OCF procedures.
- 2 General rcvy options:
1) 'Squat' -FAS hoping inertia will propel through
2) 'Milk' over the top' - Smooth aft stick 35 AOA

11

SPIN RECOVERY MODE SWITCH DEMO

***Stan** - Y, **IUT** – Sim only, **Student** – N*

A/S – 200 KCAS **ALT –** 35,000 ft AGL
CG Calculate: _______

12-1. HUD VIDEO - ON

12-2. SRM switch - RCVY

12-3. Engage SPIN MODE using PMCF technique.
- Approaching horizon catch with power

12-4. Maintain between 5 and 20 deg AOA and less than 220 kt
- Target 10 deg AOA / 200 kts

12-5. Modulate thrust to maintain level unaccelerated flight

12-6. Stabilize briefly using small lateral stick inputs
- Observe aileron deflection & adverse yaw
- All interconnects and feedbacks removed (lat stk = Aileron)
- Not truly in DEL because LEF down

12-7. Turns at max AOB of 30° - Aileron only, Rudder only, Coordinated
- Attempt heading capture

12-8. Recovery - SRM Switch – NORM
- Same procedure if meeting Abort Criteria

ABORT CRITERIA - Increasing sideforce, AOA or yaw rate tone, SRM switch – NORM

12

Appendix D
10.7 DEPARTURE TRAINING FLIGHT CARDS

F/A-18 v10.7 Departure Training Flight
Instructor Under Training Cards

Event No: ______ A/C: ________ Date: _________

Takeoff time_________ Landing time ________

FCC Load: v10.7	Loading: **Total Fuel = 11.9**
Area:	STATION 1/9 **CLEAN**
	STATION 2/8 **CLEAN**
Hot Pit/Switch:	STATION 3/7 **PYL or CLEAN**
	STATION 4/6 **CLEAN**
	STATION 5 **PYL+Tank**

LIMITS: **Departures will be only with C.G. at or forward of 23.5%**
AOA limit -6 to 25° with cg 23.5-28% (centerline)

	GEAR UP	GEAR DN
TAKEOFF GW / CG	/	/

BINGO:________________

CALL SIGNS: ____________

UHF FREQ: ____________

Pilots:________________

7 Aug 03

1

Admin

FLIGHT CLEARANCE PERMITS: *(For B & D only)*

- **INTENTIONAL DEPARTURES**
  - **C/L TANK EMPTY FOR ALL DEPARTURES**
  - **CG MUST BE AT OR FWD OF 23.5% MAC FOR DEPARTURES OR HIGH YAW RATE MANEUVERING**
  - **MIN DEPARTURE ENTRY ALTITUDE = 30,000 FT AGL**
  - **MAX MACH FOR ENTRY = 0.7 M**
- **TAILSLIDES (Incl. 15 sec at 0g)**
- **YAW RATE > 40 deg/sec only W / FCS IN CAS OR ASR**

2

MAINTENANCE CONTROL PROCEDURES

Review ADB for:
- *Any FCS issues*
- *Any recent FCF*
- *Recent Flight Control Surface Rigging*
- *Radome Patches*

PRE-FLIGHT PROCEDURES

Observe Aircraft for:
- *Radome –*
  - *Patches/imperfections in 1st 18 inches*
  - *Rain boot / seal smooth*
  - *Rub with hand to determine imperfections*
- *LEF Tape*
- *Freeplay in LEF (+/-)*
- *Aileron Shroud Seals intact*
- *Both wingfold covers installed (taco shells)*

POST-START PROCEDURES

SPIN RECOVERY MODE CHECK *(After IBIT)*

3-1. Flaps – Auto*(F/A-18D: FCS page on MPCD)*
3-2. Spin Recovery Switch – RCVY
3-3. Check DDI's – SPIN MODE ENGAGED
3-4. Flaps – LEF Down 34 deg / TEF up 0 deg
3-5. Spin Recovery Switch - NORM

FCC SOFTWARE CONFIGURATION CHECK

3-6. Verify v10.7 FCC OFP on BIT page:
F/A-18B: FCCA/B **= 120**
F/A-18D: FCCA/B **= *91C-006***

3

KNOCK-IT-OFF / ABORT CRITERIA

GROUND

- Form F inaccuracies
- Failure of SRM checks
- Incorrect flight control PROM
- Gross Abnormalities with flight controls
- MU Full
- No HUD tape (HUD tape highly desired, not required)

AIRBORNE

- Failure of RIG check
- Failure of Radome check
- Engine stalls
- FCS X's or anomalies
  Expected Cautions during Dynamic Maneuvers:
  FC AIR DAT
  V VEL
- Dive recovery initiated <20,000 ft AGL
  **** Do not fly aircraft for Departure Demo until resolution obtained from Model Manager***
  [Call Model Manager, Save HUD tapes, have Maint save ECAMS data to include Code 40, 42, & 46 data (Warnings/Cautions and PASS 1,2,&3 data) in .ADF format]

4

PRE-MANEUVER CHECKS

PRE-FIRST MANEUVER CHECKLIST

- **UHF / ICS:Hot Mike - Check**
- **Altimeter - Local**
- **Loose Items / Harness / Visor / FOD Check (*Bring minimum to cockpit, cinch lap belts)***
- **Master Mode - NAV**
- **HUD SYM – NORM**

PRE-MANEUVER CHECKLIST

- **Fuel Balance - Check**
- **CG - Check**
- **Area clear - Check**

5

AIRBORNE RIG CHECK

(As Required / Time Permitting)

A/S – 200 KCAS **ALT –** 10,000 ft

Complete Pre-first Maneuver Checklist

6-1. Ensure all zeros on the first and third lines of memory inspect UNIT 14, ADDRESS 5016
- If not re-trim laterally until between 000000 & 000600 or 177200 & 177777

6-2. Wings level, 1g flight
Slow to 200 KCAS
Throttles - Ensure Symmetric

6-3. Observe ball
- Trim out ball at each A/S prior to release, if required

6-4. Release stick & record direction and time to 30° AOB / 6 sec
- 5 deg/sec max acceptable for Dep Demo

6-5. Accel to 300 - Repeat 6-4
- Probably Stabs, TEF, Ailerons

6-6. Accel to 400 - Repeat 6-4
- Probably TEF, Ailerons

6-7. Accel to 500 - Repeat 6-4
- Predominantly LEF

ABORT CRITERIA – Observed Roll Rates > 5 deg/sec

6

HIGH AOA STATIC STABILITY DEMO & RADOME CHECK

A/S – 250 KCAS **ALT –** 35,000 ft AGL
CG Calculate: _______

7-1. HUD VIDEO - ON
7-2. Lateral & Directional Trim - Centered Ball / No rates
7-3. Throttles - IDLE (Ensure Symmetric)
7-4. DDI - Monitor FCS
- LEF and TEF should lead AOA by 2-3 deg
- ~10 AOA first indication of buffet
- ~15 AOA LEF continue down while TEF begin coming up from 17
7-5. 15 AOA - Throttles– MILITARY to reduce ROD
Sample lateral stick and rudder pedals
45 deg bank-to-bank rolls
25 AOA - 45 deg bank-to-bank rolls using full lat stick only , then full pedal only, then coordinated
- At 22 AOA aft stick forces increase, auto trim ceases
- v10.7 Control laws effective > 25 deg AOA
- Note similar aircraft response to lateral only and pedal only inputs
- Note extensive use of rudder to generate aircraft motion
45 AOA - 45 deg bank-to-bank rolls using full lat stick only , then full pedal only, then coordinated
- AOA Tone is not an A/C limit, expect to talk over tone

7-6. Radome Check - Check altitude > 25,000 ft AGL
Note initial Heading.
Continue Decel to 55+ AOA by smoothly applying full aft stick (~ 2 sec to FAS).
Hold FAS for 5 sec (No LAT/PEDAL Inputs)
Observe yaw/roll rates. Note final HDG

7-7. If Radome Checks Good – Hold FAS, Sample Lateral Stick and Pedal Inputs
7-8. Recovery – Reduce AOA, Re-establish level flight
*- Minimum Altitude **25,000 ft AGL***

ABORT CRITERIA – Departure; Distinct Yaw Accel; Spin Arrows; Hdg Change > 60 in 5 sec at FAS

7

ACCELERATED FLIGHT RADOME CHECK

A/S – 200 KCAS **ALT –** 35,000 ft AGL
CG Calculate: _______

8-1. HUD VIDEO - ON

8-2. Throttles – IDLE
- Raise nose 5-10 deg

8-3. Accelerated entry to full aft stick, left 90° AOB
- 2 sec to Full Aft Stick
- Looking outside for nose slice due to radome
- Repeat as necessary

8-4. Hold full aft stick - 5 seconds
- Observe roll, yaw, pitch rate

8-5. Repeat - Right 90° AOB.
- Minimum Altitude 25,000 ft AGL
- Observe LEF/TEF operation on FCS page
- Symmetrical extension and rate of extension
- HDU failure will be LEF not extending or ratcheting

Note: If abnormal tendencies, yaw rate tone, spin logic activates - NEUTRALIZE LONG STICK
- If continuing, you know what direction the aircraft has a propensity to go, plan your ASRM demo the same direction

ABORT CRITERIA – Departure; Distinct Yaw Accel; Spin Arrows; Tendency to roll upright with roll attitude change > 60 deg in 5 seconds; Yaw tone after AOA <35 during recovery

8

AUTOMATIC SPIN RECOVERY MODE DEMO

A/S – 150 KCAS **ALT –** 35,000 ft AGL
CG Calculate: _______

9-1. HUD VIDEO - ON
9-2. Slowly reduce both throttles to IDLE
9-3. Set 15 deg pitch attitude max and hold

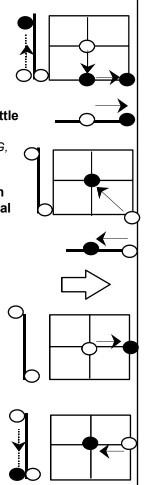
9-4. At AOA tone onset- Increase thrust on one engine smoothly to MAX, smoothly apply aft stick.
Full Aft Stick when nose passes horizon
Full Lateral Stick and Pedal opposite throttle
- Avoid nose high entry, may become oscillatory
- Use two hands on aft stick otherwise during PSG, stall will break if stick moves off aft stop

9-5. Hold in Stick and Pedal for 1.5 turns, then smoothly neutralize Lateral Stick and Pedal
-Observe spin arrows after neutralizing

9-6. Apply Lateral Stick with Spin Arrow
Note when Spin Arrow disappears
-Minimum Altitude 25,000 ft AGL

9-7. Complete NATOPS Recovery
- When yaw rate stops – smoothly neutral or expect *opposite direction departure*
- Verbalize procedures (have them recite in brief),
- Simultaneously bring throttle to idle with lat/long stick input

9-8. Engines – Check



ABORT CRITERIA – Increasing oscillatory motion

9

VERTICAL DEPARTURES

A/S – 300 KCAS **ALT –** 30,000 ft AGL
CG Calculate: _______

10-1. HUD VIDEO - ON

10-2. Smoothly pull nose up to 70° to 90° Pitch reference waterline (1 % RULE)
- HUD symbology may float 40-70 deg NU, reference outside

10-3. Use forward stick to maintain nose position
- Less than 50 kts 'stir the pot' to show controls ineffective

10-4. Thrust - IDLE at departure
- Increase in surge margin

10-5. Recovery - NATOPS OCF
- Verbalize procedures, grab towel racks, feet flat on floor

10-6. Engines - Check

10-7. Repeat - Attempt to recover at 100 kt
- Don't give up trying to reach the horizon until the nose stops tracking, same as controls not responding, at that time OCF procedures.
- 2 General rcvy options:
1) 'Squat' -FAS hoping inertia will propel through
2) 'Milk' over the top' - Smooth aft stick 35 AOA

10

VITA

David Joohyung Park was born in Syracuse, New York on December 28, 1968. He was raised in the United States until the age of six. From 1975 to 1983, he lived in Seoul, South Korea and attended None Hyun Elementary School and Seo Cho Middle School up to eighth grade. He then moved to Glenview, Illinois and graduated from Springman Junior High School in 1983 and Glenbrook South High School in 1987. From there, he went on to the California Institute of Technology, Pasadena, California and received a B.S. in Engineering and Applied Science with emphasis in Aeronautics in 1991. Commissioned in the United States Marine Corps in 1992, he was designated a Naval Aviator in 1995 and F/A-18 pilot in 1996. His Fleet Marine Force tours included assignments with VMFA-212 (F/A-18C) and VMFA(AW)-242 (F/A-18D). During his fleet tours, he completed the Navy Fighter Weapons School (TOPGUN), Fallon, Nevada. Following his fleet tours, he completed United States Air Force Test Pilot School, Edwards, California in 2002. From 2002 to 2004, he was a test pilot and project officer with the Air Test and Evaluation Squadron 23 (VX-23), Patuxent River, Maryland. His projects included numerous stores/weapon separation, loads testing, systems testing, and flight control computer testing in the F/A-18A-D Hornet and F/A-18E/F Super Hornet. He was also involved with the development of F-35 Joint Strike Fighter.

He is currently assigned to United States Navy Test Pilot School as a fixed-wing instructor pilot. His areas of specialty are in Departure Demonstration, Aircraft Loads Testing, Weapon Separation, and Aircraft Systems Testing.

He is married to Lisa Kim of Fullerton, California. They reside in Mechanicsville, Maryland.