UNITED STATES AIR FORCE AIRCRAFT ACCIDENT INVESTIGATION BOARD REPORT

F-15D, T/N 86-0182

493D FIGHTER SQUADRON
48TH FIGHTER WING
RAF LAKENHEATH, UNITED KINGDOM

LOCATION: NEAR SPALDING, LINCOLNSHIRE, UNITED KINGDOM

DATE OF ACCIDENT: 8 OCTOBER 2014

BOARD PRESIDENT: [redacted]

CONDUCTED IN ACCORDANCE WITH AIR FORCE INSTRUCTION 51-503

EXECUTIVE SUMMARY

AIRCRAFT ACCIDENT INVESTIGATION

F-15D, T/N 86-0182
NEAR SPALDING, LINCOLNSHIRE, UNITED KINGDOM
8 OCTOBER 2014

On 8 October 2014 at 15:26 hours local time, an F-15D aircraft, tail number (T/N) 86-0182, assigned to the 493d Fighter Squadron, 48th Fighter Wing, RAF Lakenheath, entered into a spin and crashed while conducting a basic fighter maneuvers (BFM) training mission in East Anglia airspace north of RAF Lakenheath. During the mission's final planned engagement, the mishap pilot (MP) maneuvered the mishap aircraft (MA) into a series of descending vertical maneuvers. At 15,200 feet mean sea level (MSL), the MP executed an abrupt aft-stick pull that spiked the MA's angle of attack (AOA). The MA then experienced an uncommanded nose-slice to the left, constituting a loss of aircraft control. The MA then entered a flat spin, reaching a peak yaw rate of 111° per second at approximately 12,200 feet MSL. The MP attempted to regain aircraft control by following MA Spin Recovery Display commands. Without indications of aircraft recovery, the MP ejected at 5,450 feet MSL, sustaining minor injuries. There were no civilian injuries or fatalities. The MA was destroyed upon impact at an estimated cost of $44,608,743.00. Private property damage included fire and impact damage to a farmer's field.

Post-mishap analysis revealed a larger than normal gap between the body of the radome, or aircraft nose, and the metallic cover for the tip of the radome, called a nose cap. The sealant used to secure the nose cap in place extruded from under the nose cap. This sealant extended onto the radome body and formed an uneven aerodynamic surface.

A series of aerodynamic studies has shown that similar radome imperfections are capable of generating yaw forces that can both induce a spin and delay spin recovery. These radome imperfections do not significantly affect aircraft performance except in infrequent cases where a pilot commands extreme AOA at certain airspeeds. In this mishap, the MP's abrupt aft-stick pull placed the MA in this flight regime. Imperfections of the MA's radome then generated sufficient yaw to cause a spin and delay the MA's recovery beyond the prescribed bailout altitude for an uncontrolled aircraft. Additionally, in comparison with the single seat F-15C, two seat F-15Ds such as the MA can exhibit reduced yaw stability under conditions of rapid AOA onset rates.

The Accident Investigation Board President found by clear and convincing evidence that the mishap was caused by a combination of two factors. First, the MP's abrupt aft-stick pull placed the MA in an extreme AOA flight regime. Second, while in that aerodynamic regime, imperfections with the radome's nose cap assembly generated sufficient yaw forces for a spin entry and delayed spin recovery beyond the minimum uncontrolled bailout altitude. By a preponderance of evidence, the Board President also found that the inherent reduced stability of the F-15D model was a significant contributing factor to the mishap.

SUMMARY OF FACTS AND STATEMENT OF OPINION
F-15D, T/N 86-0182
8 OCTOBER 2014

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COMMONLY USED ACRONYMS AND ABBREVIATIONS

3 AF	Third Air Force
48 FW	48th Fighter Wing
48 OG	48th Operations Group
493 FS	493d Fighter Squadron
AB	Afterburner
ACCES	Attenuating Custom Communications Earpiece System
ACES II	Advanced Concept Ejection Seat II
ADI	Attitude Director Indicator
ADO	Assistant Director of Operations
AETC	Air Education Training Command
AF	Air Force
AFAFRICA	Air Forces Africa
AFB	Air Force Base
AFE	Aircrew Flight Equipment
AFI	Air Force Instruction
AFIP	Air Force Institute of Pathology
AFAFRICA	Air Forces Africa
AFMAN	Air Force Manual
AFMES	Armed Forces Medical Examiner System
AFPAM	Air Force Pamphlet
AFSC	Air Force Specialty Code
AFTO	Air Force Technical Order
AFTTP	Air Force Tactics, Techniques, Procedures
AGE	Aerospace Ground Equipment
AGL	Above Ground Level
AIB	Accident Investigation Board
AIM	Air Intercept Missile
AMXS	Aircraft Maintenance Squadron
AOA	Angle of Attack
ARMS	Aviation Resource Management System
ATC	Air Traffic Control
AUTO	Automatic
AUX	Auxiliary
B Course	Basic Qualification Course
BFM	Basic Fighter Maneuver
BINGO	Minimum Fuel Required to RTB
BIT	Built-In-Test
BMC	Basic Mission Capable
BPO	Basic Post-Flight Inspection
Capt	Captain
CAF	Combat Air Forces
CAN	Cannibalized
CATM	Captive Air Training Missile
CAS	Control Augmentation System
CGO	Company Grade Officer
COMM	Communication
CONUS	Continental United States
CP	Command Post
CPU	Cockpit Units of AOA
CSAR	Combat Search and Rescue
CSEL	Combat Survivor Evader Locator
Dash One	TO 1F-15A-1 Flight Manual
DO	Director of Operations
DoD HFACS	Department of Defense Human Factors Analysis and Classification
ELT	Emergency Locator Transmitter
EFT	Engine Flight Time
EOR	End of Runway
EP	Emergency Procedures
F	Fahrenheit
ETAR	Engineering Technical Assistance Request
FCIF	Flight Crew Information File
FDP	Flight Duty Period
FERMS	Flight Equipment Records Management System
FLUG	Flight Lead Upgrade
FOD	Foreign Object Damage
FS	Fighter Squadron
FSS	Force Support Squadron
FTU	Flying Training Unit
G	Gravitational Force
G-Suit	Anti-G Garment
GPS	Global Positioning System
GX	G-Awareness Exercise
HF	Human Factor
hrs	Hours
HUD	Heads Up Display
IAW	In Accordance With
IMDS	Integrated Maintenance Data System
IP	Instructor Pilot
K	Thousand
KCAS	Knots Calibrated Airspeed
KIAS	Knots Indicated Air Speed
kts	knots
L	Local Time
LOX	Liquid Oxygen
LPU	Life Preserver Unit
Lt Col	Lieutenant Colonel
MA	Mishap Aircraft
Maj	Major
MAJCOM	Major Command
MAN	Manual
MC	Mishap Aircraft Crew Chief
MDG	Medical Group
MDS	Mission Design Series
MF	Mishap Flight
MFLB	Mishap Flight Lead Backseater
MFLP	Mishap Flight Lead Pilot
MICAP	Mission Impaired Capability Awaiting Parts
MIL or MIL POWER	Military Power
MOA	Military Operating Area
MOC	Maintenance Operations Center
MP	Mishap Pilot

MPCD	Multi-Purpose Color Display
MQT	Mission Qualifying Training
MS	Mishap Sortie
MSL	Mean Sea Level
NATO	North Atlantic Treaty Organization
NCOIC	Non-Commissioned Officer in Charge
NOTAMS	Notices to Airmen
OFP	Operational Flight Program
OG	Operations Group
Ops Check	Operations Check
Ops Sup	Operations Supervisor
Ops Tempo	Operations Tempo
ORM	Operational Risk Management
OSS	Operation Support Squadron
PA	Public Affairs
PCL	T-6 Power Control Lever
PHA	Periodic Health Assessment
PLB	Personnel Locator Beacon
PLF	Parachute Landing Fall
PR	Preflight
PRD	Pilot Reported Discrepancy
QA	Quality Assurance
QUAL	Qualification
RAF	Royal Air Force
RAPCON	Radar Approach Control
RED X	Safety of Flight
RMM	Removable Memory Module
RPM	Revolutions per Minute
R-Squared (or R^2)	Remove and Replace
RTB	Return-To-Base
SAR	Search and Rescue
SIB	Safety Investigation Board
S/N	Serial Number
SOF	Supervisor of Flying
Sortie	Flight
SPO	System Program Office
SRD	Spin Recovery Display
TACAN	Tactical Aid to Navigation
TCTO	Time Compliance Technical Order
TDY	Temporary Duty
TH	Thru-Flight
T/N	Tail Number
T.O.	Technical Order
Top 3	Operations Supervisor
Tox Screening	Toxicology Screening
TR	Training Rules
TX	Transition Course
UHF	Ultra High Frequency
UK	United Kingdom
URITS	USAFE Rangeless Interim Training System
US	United States
USAFE	United States Air Forces Europe
USAFRICOM	United States Africa Command
U.S.C.	United States Code
USAF	United States Air Force
USEUCOM	United States European Command
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
VSD	Vertical Situation Display
VMC	Visual Meteorological Conditions
WDO	Weapons Duty Officer
WSO	Weapons System Operator
Z	Zulu or Greenwich Mean Time

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 3 November 2014, General Frank Gorenc, Commander, United States Air Forces in Europe – Air Forces Africa (USAFE-AFAFRICA), appointed Colonel [redacted] to conduct an aircraft accident investigation of a mishap that occurred on 8 October 2014 involving an F-15D aircraft, tail number (T/N) 86-0182, near Spalding, Lincolnshire, United Kingdom (UK). General Gorenc also appointed a Major Pilot Member, Captain Medical Member, Captain Legal Advisor, Senior Master Sergeant Maintenance Member, and a Staff Sergeant Recorder. The aircraft accident investigation was conducted in accordance with Air Force Instruction (AFI) 51-503, *Aerospace Accident Investigations*, and was convened at Royal Air Force (RAF) Lakenheath, UK, from 8 November 2014 through 27 November 2014. The Accident Investigation Board (AIB) members then continued to work on the report from their regular duty locations and completed their work on 3 December 2014. (Tab Y-1 to Y-2).

b. Purpose

This is a legal investigation convened to inquire into the facts surrounding the aircraft accident, to prepare a publicly-releasable report, and to gather and preserve all available evidence for use in litigation, claims, disciplinary actions, administrative proceedings, and for other purposes.

2. ACCIDENT SUMMARY

On 8 October 2014 at 15:26 hours local time (L), an F-15D aircraft, T/N 86-0182, assigned to the 493d Fighter Squadron (493 FS), 48th Fighter Wing (48 FW), RAF Lakenheath, entered into a spin and crashed while conducting a basic fighter maneuvers (BFM) training mission in East Anglia airspace north of RAF Lakenheath (Tab H-2, J-20, K-8, K-18). During the mission's third and final planned engagement, the mishap pilot (MP) maneuvered the mishap aircraft (MA) into a series of descending vertical maneuvers (Tab HH-1). At 15,200 feet mean sea level (MSL), the MP executed an abrupt aft-stick pull that spiked the MA's angle of attack (AOA) (Tab HH-1). The MA experienced an uncommanded nose-slice to the left, constituting a loss of aircraft control. The MA then entered into a flat spin, reaching a peak yaw rate of 111° per second at approximately 12,200 feet MSL (Tab J-18). The MP attempted to regain aircraft control by following MA's Spin Recovery Display (SRD) commands (Tab V-1.8). Without indications of aircraft recovery, the MP ejected at 5,450 feet MSL, sustaining minor injuries (Tab H-2, J-18, EE-1). The MA crashed approximately three miles southeast of Spalding, Lincolnshire, UK, in a farmer's field (Tab S-12). There were no civilian injuries or fatalities. The MA was destroyed upon impact with a cost to the United States government estimated at $44,608,743.00 (Tab P-4). Private property damage included fire and impact damage to a local farmer's field, and an estimated environmental clean-up cost of $604,405.25 (Tab P-2, FF-5).

3. BACKGROUND

Both the MP and the MA were assigned to the 493 FS, 48 FW, Third Air Force (3 AF), USAFE-AFAFRICA, and stationed at RAF Lakenheath, UK (Tab G-2, K-5, K-44).

a. United States Air Forces in Europe – Air Forces Africa (USAFE-AFAFRICA)

Headquartered at Ramstein Air Base, Germany, USAFE-AFAFRICA is a major command of the U.S. Air Force (AF). It is also the air component for two Department of Defense unified combatant commands: the United States European Command (USEUCOM), which serves as the US component of the North Atlantic Treaty Organization (NATO), and the United States Africa Command (USAFRICOM). As the air component for both USEUCOM and USAFRICOM, USAFE-AFAFRICA executes AF, USEUCOM and USAFRICOM missions with forward-based airpower and infrastructure to conduct and enable theater and global operations. USAFE-AFAFRICA directs air operations in a theater spanning three continents, covering more than 15 million square miles, containing 104 independent states, possessing more than one-fifth of the world's population, and more than a quarter of the world's gross domestic product. (Tab CC-1.1).

b. Third Air Force (3 AF)

3 AF is USAFE-AFAFRICA's numbered air component for USEUCOM and USAFRICOM. Headquartered at Ramstein Air Base, Germany, 3 AF plans, executes, and assesses a full spectrum of airpower operations. The command consists of its headquarters operations directorate, the 603d Air and Space Operations Center, and 10 wings comprised of more than 33,000 personnel. (Tab CC-2.1 to CC-2.2).

c. 48th Fighter Wing (48 FW)

The mission of the 48 FW is to provide responsive combat airpower, support, and services to meet the international objectives of the United States and its allies. As USAFE-AFAFRICA's only F-15 fighter wing, the 48 FW provides unique air combat capability to the fight. In addition, the 48 FW is host to HH-60G Pave Hawk helicopters, which provide combat and civil search and rescue capabilities, medical evacuation, disaster response, and humanitarian assistance. The 48 FW is located in the UK at RAF Lakenheath, approximately 70 miles northeast of London. (Tab CC-3.1).

d. 48th Operations Group (48 OG)

The 48 OG consists of five squadrons of F-15C/D/E aircraft, HH-60G helicopters, and personnel capable of accomplishing fighter and rescue operations worldwide. The 48 OG prepares aircrew and support personnel to accomplish war plans and contingency operations for USEUCOM, USAFRICOM, NATO, and USAFE-AFAFRICA. In addition, the 48 OG provides training, equipment, scheduling, analysis, weather, intelligence, standardization and evaluation, and command and control for efficient flying operations. (Tab CC-4.1).

e. 493d Fighter Squadron (493 FS)

The 493 FS is a combat-ready F-15C/D squadron capable of executing air superiority and air defense missions in support of war plans and contingency operations for USAFE-AFAFRICA, USEUCOM, USAFRICOM, and NATO. The 493 FS employs the full array of air-to-air weapons and electronic identification systems while maintaining the ability to rapidly generate, deploy, and sustain operations to execute wartime and peacetime taskings in any theater of operations in the world. (Tab CC-4.1).

f. F-15 Eagle

The Eagle is an all-weather, extremely maneuverable, tactical fighter aircraft designed to permit the AF to gain and maintain air supremacy over the battlefield. Eagle pilots utilize the aircraft's maneuverability, acceleration, range, weapons, and avionics to achieve desired effects in aerial combat. The F-15 has electronic systems and weaponry to detect, acquire, track and attack enemy aircraft while operating in friendly or enemy-controlled airspace. The single-seat F-15C and two-seat F-15D entered the AF inventory beginning in 1979. (Tab CC-5.1 to CC-5.2).

4. SEQUENCE OF EVENTS

a. Mission

On 8 October 2014, the mishap flight (MF), a two-ship formation of F-15D aircraft, was scheduled for a BFM training mission and assigned the formation call sign "HITMAN" (Tab K-19). The mishap flight lead pilot (MFLP), flying as HITMAN 31, was a current and qualified F-15 Four-ship Flight Lead (Tab G-85). HITMAN 31 also had a rear cockpit passenger, the mishap flight lead backseater (MFLB), who participated as part of the 48 OG incentive/orientation program (Tab G-86). The MP, flying as HITMAN 32, was a current and qualified F-15 Wingman (Tab G-85). The 493 FS Operations Supervisor (Top 3), charged with overseeing daily operations, authorized the mission in accordance with AFI 11-401, *Aviation Management* (Tab K-2 to K-5).

b. Planning

The MFLP and MP completed all required mission planning tasks and attended the 493 FS mass briefing on 8 October 2014 (Tab K-7 to K-17). The mass briefing covered all pre-mission brief elements in accordance with AFI 11-2F-15 Vol. 3, *F-15—Operations Procedures*; Lakenheath

Instruction 11-2F-15-E Vol. 3, *Flying Operations: Local Operating Procedures*; and AFI 11-214, *Air Operations Rules and Procedures*. Following the mass briefing, the MF conducted a short briefing to discuss specific mission objectives (Tab R-4 to R-5).

c. Preflight

The Top 3 provided a "step briefing" to the MF as they prepared to depart the squadron building. This briefing covered all required items to include updates on weather conditions, Notices to Airmen information, airfield status, and maintenance data (Tab R-5). Afterwards, the MP proceeded to the MA's parking location where he reviewed maintenance documentation and performed a normal preflight inspection of the MA. He confirmed the MA's configuration and noted no problems (Tab V-1.20, V-3.5). Maintenance documents confirmed the aircraft was properly balanced and configured with wing pylons, three training missiles, instrumentation pod, and no external fuel tanks (Tab J-3 to J-4). This configuration evenly distributed the weight of these externally mounted items to promote aircraft stability in the yaw-axis and roll-axis (e.g., left/right movement of the aircraft nose and bank angle of the aircraft wings, respectively).

In addition, the MP installed the removable memory module (RMM) as part of his normal pre-engine start checks (Tab V-1.27). The RMM records aircraft parameters (such as roll, pitch, yaw—also known as parametric data) and video feeds from certain cockpit displays for post-flight analysis. The MA RMM, successfully recovered from the crash site, provided investigators detailed access to the MA's parametric data and Heads Up Display (HUD) video throughout the duration of the mishap mission.

All engine-start, preflight, taxi, and end-of-runway checks were normal (Tab V-1.3, DD-1).

d. Summary of Accident

The MF took off at 15:02L and proceeded to the East Anglia airspace located north of RAF Lakenheath (Tab K-8, K-42, V-1.3). Once established in the airspace, the MF completed several routine flight checks, to include an operations (ops) check (Tab V-1.4). The ops check is a periodic check of aircraft systems (engines, fuel, oxygen, etc.) performed by the pilot for safety of flight. The checks indicated all systems were functioning properly (Tab V-1.4). The MF also conducted ops checks periodically throughout the mission without incident (Tab V-1.4, HH-1).

Upon completion of the first ops check, the MF proceeded with the planned BFM training (Tab V-1.4, HH-1). BFM training allows a fighter pilot to practice combat maneuvering, from either an offensive or a defensive position, against a single opponent. Fighter aircraft begin BFM engagements from standardized parameters of speed, altitude, and range relative to each other. Typically, F-15s fly either short-range (3000 feet range between aircraft) or medium-range (6000 feet between aircraft) setups. The MF conducted two medium-range BFM engagements that proceeded normally (Tab V-1.4).

At 15:26:27L, the MF initiated the third and final BFM engagement, a short-range defensive engagement for the MP, beginning at 18,000 feet MSL (Tab V-1.5, HH-1). The MP executed a slightly nose-low, 7g, defensive turn at the beginning of the engagement (Tab V-1.5, HH-1). The MP then selected maximum afterburner (MAX AB) on both engines and executed a turn reversal (Tab V-1.5). The MFLP, as the offensive opponent, remained safely behind the MP while attempting to achieve a position to employ simulated weapons (Tab R-6, V-1.5).

After the turn reversal, the MP moved the throttles to just below MILITARY power and executed two nose-low vertical maneuvers, losing approximately 2,000 feet of altitude (Tab V-1.6, HH-1). These maneuvers were consistent with a common BFM tactic for the defensive fighter known as "vertical jinks." At the end of these jinks and with the throttles just below MILITARY power, the MP executed an abrupt aft-stick pull while descending through 15,200 feet MSL at 151 knots calibrated airspeed (KCAS) and approximately 45° nose-low (Tab HH-1, V-1.6). As a result, the MA nose rose 20°, the HUD display spiked at 45 cockpit units (CPU), and the MA entered wing rock (Tab GG-1.3, HH-1, BB-2.10, BB-6.2). Wing rock is the term for bank oscillations that occur when an F-15 is in a stalled condition. RMM data showed the MA's AOA peaked at 54 CPU (Tab GG-1.3).

AOA is a measure of the angle between the oncoming air and a line of reference on the aircraft such as the aircraft's fuselage centerline. The F-15 displays AOA in CPU, which roughly equates to the AOA value + 10. Additionally, although the HUD is limited to a displayed value of 45 CPU, the F-15 is capable of achieving much higher AOA values. These values are recorded and available via RMM parametric data (Tab GG-1.3).

Although the MP did not remember making this aft-stick pull, parametric data confirms a pitch change and rapid increase in AOA indicating an abrupt aft-stick movement (Tab V-1.12, GG-1.3). The MA's HUD video and parametric data also indicate the aft-stick pull was made purely along the longitudinal axis (i.e., fore-aft stick position) and there were no rudder inputs during the move (Tab GG-1.3). Any lateral stick or rudder inputs during this maneuver (the Flight Manual definition of "improper control inputs") would have generated yaw, sideslip, or bank angle changes not evident in the MA's parametric data during the aft-stick pull. (Tab BB-2.14, GG-1.3).

An aft-stick pull at this point in the engagement is consistent with an attempt to fly the last portion of a vertical jink where the defensive fighter attempts to generate closure with his opponent. Normally, however, this maneuver should be flown at the maximum performance limit of the aircraft to create the greatest possible challenge to the other aircraft (Tab BB-6.2, BB-6.3). This means that an F-15 pilot will use just enough aft-stick pressure to turn the aircraft optimally without stalling and without overshooting the desired AOA. Stalling the aircraft (as indicated by wing rock) results in poor turn performance and ineffective BFM maneuvering. Overshooting the desired AOA (i.e., "spiking" the AOA) can put the aircraft at an AOA level that increases the F-15's susceptibility to departure from controlled flight, under certain conditions. (Tab BB-6.2).

It is particularly important in the two-seat F-15D model, as compared to the single-seat F-15C, to avoid spiking the aircraft's AOA. According to the F-15 flight manual, "[d]uring early flight testing, two-seat F-15s were observed to exhibit a significant decrease in directional stability with a rapid onset of AOA above 34 CPU at low or IDLE power settings" (Tab BB-2.10). Directional stability is a term that refers to aircraft response about the yaw axis (Tab BB-2.9). Although the MA power setting was higher than that specified in the flight manual, the MA's parametric data indicates that the abrupt aft-stick pull was sufficient to spike the AOA above 50 CPU (Tab V-1.6, GG-1.3).

Spiking the aircraft's AOA can also place the aircraft in a situation whereby imperfections of the radome (the composite structure forming the nose of the aircraft) can cause departures from controlled flight. A departure is defined as a large, uncommanded flight path change, and constitutes a loss of aircraft control (Tab J-20, BB-2.5). Air Force Tactics, Techniques, and Procedures (AFTTP) 3-3.F-15, *Combat Aircraft Fundamentals* states:

> Normally, even without imperfections, the airflow around the radome begins to separate at very high AOA levels (i.e., typically 65 to 70 CPU). The separation occurs unevenly, causing a slight yaw due to the pressure differential… A 27-foot moment arm from the [aircraft's center of gravity] to the nose multiplies this small yawing force, making it significant enough to overcome inherent lateral-directional stability. Typically, pilots do not reach these AOA levels, nor could they sustain them long enough to depart. But, with imperfections in the radome accelerating this separation, pilots can see significant yaw rates at AOA levels as low as 50 CPU (Tab BB-6.4)

After the MP's abrupt aft-stick pull, the MA's nose made an uncommanded slice to the left (Tab J-18, GG-1.1, HH-1). The SRD initiated 1.6 seconds later when the yaw rate exceeded 60° per second (Tab J-18, HH-1). The SRD activates when the F-15 central computer detects a spin condition (See Figure 1; Tab BB-2.2).

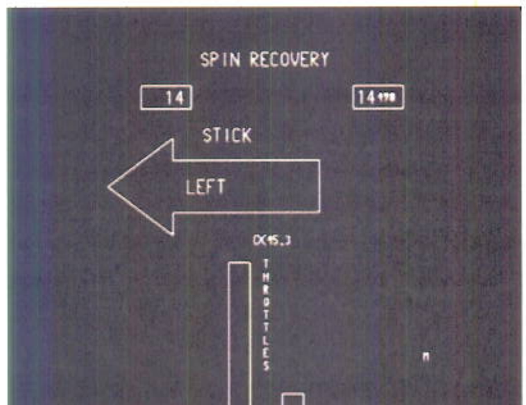

Figure 1: F-15 MPCD Spin Recovery Display (Tab HH-1)

Six seconds after the MA's departure from controlled flight, the MP called "HITMAN Knock-it-off." The MFLP responded by transmitting "Knock it off," and then directed the MP to "smoothly neutralize the controls." (Tab II-1.1). He did this to remind to the MP to execute F-15 out-of-control recovery procedures (Tab BB-2.6, II-1.1).

The MP input full right rudder, reduced the throttles to IDLE, and ensured the MA's speed brake was retracted. The MP assessed the MA was in a spin and followed by inputting full lateral stick (aileron is the F-15's primary anti-spin flight control surface) in the direction of spin with the stick longitudinally neutral. (Tab V-1.6 to V-1.7). He then briefly moved the left throttle to MAX, corrected by selecting MIL power on that engine, and maintained the right throttle in the IDLE position. These are the correct anti-spin flight control positions per F-15 flight manual (Tab V-1.8, BB-2.5 to BB-2.8).

Ten seconds after the initial nose slice and passing 12,200 feet MSL, the MA's yaw rate peaked at 111° per second (See Figure 2; Tab J-18, GG-1.2). At this point, the MA was established in a flat erect spin, as defined in the F-15 Flight Manual (See Figure 2 on the next page for a depiction of yaw rate throughout the mishap sequence; Tab V-1.6, BB-2.16). Even with full anti-spin flight controls, the MA spin rate slowed at only 1° per second[2] (Tab J-24). At this rate of recovery, it would take between 10,000 and 15,000 feet for the MA to recover (Tab J-27).

The MP testified that he perceived the yaw rate decay (i.e., the degree to which the spin was slowing) as indicating imminent recovery, however, the MA never actually recovered as quickly as he expected (Tab V-1.7). At approximately 10,000 feet MSL, the MP momentarily released the control stick to validate the longitudinally neutral position before reapplying full left (anti-spin) aileron (Tab V-1.7, V-1.25). This stick movement momentarily neutralized the ailerons and took out anti-spin flight controls. As a result, the MA experienced a slight increase in yaw rate and an overall slight reduction in the yaw's rate of decay through the remainder of the spin (Tab J-18).

F-15 aerodynamic academic papers warn against taking out anti-spin controls once they are established. Instead, it counsels patience and states that taking out those controls will reset the "recovery clock" (Tab BB-5.2). This warning implies that taking out anti-spin controls will remove any spin-recovery momentum achieved up to that point, and that any subsequent recovery attempt will have to rebuild that momentum from the beginning. However, in this case, the MA's parametric data suggests that, from the outset of the spin, the aircraft was unlikely to recover prior to the prescribed uncontrolled bailout (or, ejection) altitude of 6,000 feet above ground level (AGL) (Tab K-8, BB-2.8). Thus, the evidence suggests that the MP's decision to momentarily take out anti-spin controls was not a factor in this mishap.

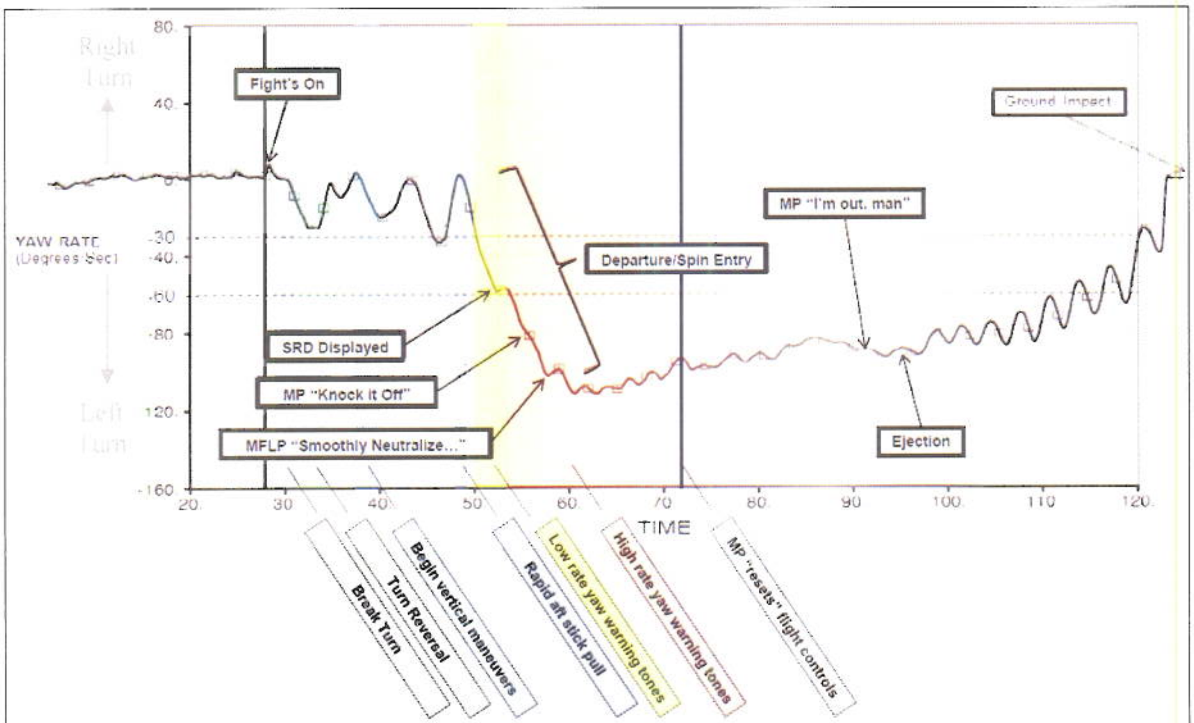

Figure 2: MA Yaw Rate During Final Engagement

Throughout the course of the spin, the MP elected not to lower the landing gear, the last step of the F-15 Out-of-Control/Departure Recovery Checklist prior to ejection. At first, he made this decision because he perceived yaw rate decay as indicating imminent spin recovery. The next time the MP considered lowering the landing gear, the MA was nearing 6,000 feet AGL, so he instead shifted his attention to executing proper ejection procedures. (Tab V-1.13). Lowering the landing gear during a spin ensures full aileron deflection regardless of the control stick's fore-aft position (Tab BB-2.7). Full aileron deflection, which is required for a successful spin recovery, is provided any time the spin rate exceeds 60° per second. However, as the spin slows below 60° per second, the only time full aileron deflection is available is when the stick is in the perfectly neutral fore-aft position, or when the landing gear is lowered. (Tab BB-2.16). Thus, lowering the landing gear would have been an important step in the spin recovery process had the spin slowed below 60° per second. The spin rate, however, did not slow to below 60° per second until well after the MP ejected from the MA (Tab BB-2.16). In other words, full anti-spin aileron deflection was available throughout all of the MP's spin recovery efforts. There is no evidence to suggest that lowering the landing gear would have accelerated the MP's spin recovery efforts. Therefore, the MP's omission of this step in the Out-Of-Control/Departure Recovery Checklist was not a factor in this mishap.

Beginning at 11,000 feet, the MFLP began calling out the MA's altitude to help the MP maintain situational awareness (Tab V-1.8). When the MFLP called "7,000", the MP concluded he would be unable to recover by 6,000 feet AGL and prepared for ejection (Tab V-1.8). Passing 6,000 feet MSL and at 15:28:04L, the MP transmitted, "I'm out man" and initiated the ejection sequence (Tab V-1.8, HH-1, II-1.2).

e. Impact

The MA impacted the ground in a field at 15:28:38L at N52-45.4 E000-06.9, approximately three miles southeast of Spalding, Lincolnshire, UK (See Figure 3; Tab S-12, GG-2). The landing gear, flaps, and speedbrake were all retracted at impact (Tab J-5, J-10, J-13). MA parameters at impact were 105 KCAS, 50° nose-low, in 45° left bank, and on a northwest heading (Tab HH-1). There were no civilian injuries or fatalities (Tab FF-5). Private property damage included fire and impact damage to a local farmer's field (Tab P-2, FF-5).

Figure 3: MA Crash Site

f. Egress and Aircrew Flight Equipment (AFE)

The MP ejected at 5,450 feet MSL while the MA was still established in a spin (Tab J-18). The MP's Advanced Concept Ejection Seat II functioned normally and the parachute deployed immediately after ejection. According to the MP, the egress and survival equipment performed as designed (Tab V-1.9).

All egress and AFE equipment inspections were current at the time of the mishap (Tab H-12 to H-18). In addition, MP, MFLP, and MFLB egress training requirements were all current (Tab G-28, G-55, G-86, H-18). The ejection system performed as intended (Tab H-10).

g. Search and Rescue (SAR)

Immediately after ejection, the MFLP called the RAF Lakenheath Supervisor of Flying (SOF) and SWANWICK MIL, the overseeing British air traffic control agency (Tab N-6, N-21, R-6, R-26). The MFLP informed them that the MP ejected and that he was assuming on-scene commander duties (Tab N-6, N-21, R-6, R-26). On-scene commander duties include orchestrating airborne efforts to locate and recover a survivor. CYLON flight, a nearby two-ship formation of F-15Cs, responded and briefly took over on-scene command when the MFLP became low on fuel and had to return to base (Tab N-7 to N-8, R-7, R-26). JUNGLE flight, a four-ship formation of F-15Es, also provided assistance once notified of the mishap by SWANWICK MIL (Tab N-27). Shortly after arriving on scene, JUNGLE 81 relieved CYLON 21 as on-scene commander (Tab N-10). At 15:37:02L, JUNGLE 81 spotted the MA wreckage near the town of Spalding, Lincolnshire, and relayed the coordinates to the SOF (Tab N-9).

After landing safely on the ground, the MP borrowed a cell phone from a local British citizen who responded to the scene. The MP called the SOF to report his condition and then used the handheld radio from his survival vest to call JUNGLE 81 and relay his status and position (Tab V-1.10, N-11).

Meanwhile, JOLLY 11, an HH-60G helicopter assigned to the 56th Rescue Squadron at RAF Lakenheath, responded to the crash (Tab N-27). 26 minutes after ejection, JOLLY 11 picked up the MP and flew him back to RAF Lakenheath where the emergency room at the 48th Medical Group (48 MDG) evaluated him for injuries (Tab N-30, V-1.11, EE-1).

h. Recovery of Remains

Not applicable.

5. MAINTENANCE

a. Forms Documentation

At the time of the mishap, the MA total aircraft time was 6,536.7 hours (Tab D-3).

A detailed review of active and historical Air Force Technical Order (AFTO) Form 781 series aircraft maintenance records revealed no discrepancies to indicate engine, mechanical, flight control, or other problems existed with the MA (Tab D-3 to D-20). A thorough review of the active AFTO 781 forms and AFTO 781 historical records dating back to 10 July 2014 revealed no evidence of mechanical, structural, or electrical failure (Tab DD-2.1 to DD-2.34). The Integrated Maintenance Data System historical records for 30 days prior to the mishap validated and confirmed all form entries (Tab DD-2.1 to DD-2.11). None of the open Time Compliance Technical Orders (TCTO) in the active forms restricted the MA from flying. A review of the historical records showed that maintenance technicians completed all TCTOs within proper technical guidance (Tab D-41, DD-1).

The MA flew 30 missions between 9 September and 8 October 2014. 27 of those flights were classified as Code 1 (no significant maintenance problems noted), 0 were Code 2 (aircraft experienced degraded system performance, but is still flyable), and 3 were Code 3 (significant problems require repair before the aircraft can fly again) (Tab DD-5, DD-6.1). The MA's reported Code 3 discrepancies and resulting maintenance actions during that time were as follows (Tab DD-2.2, DD-2.7, DD-2.8, DD-2.10, DD-6.1, and DD-7):

Date	Discrepancy	MX Actions
10 September 2014	Vertical Velocity Indicator (VVI) displayed incorrect vertical speed	Replaced the indicator and returned the aircraft to service
24 September 2014	Fuel transfer malfunction with an internal fuel imbalance of 300-400lbs—right wing heavy	Performed operational checks on the fuel system, found no defects, and returned the MA to service
2 October 2014	Over-G (the pilot exceeded G-limits of the aircraft)	Performed required inspections, found no defects, and the MA returned to service

Because the fuel system can create aircraft lateral asymmetry which can increase the potential of aircraft departure from controlled flight, the AIB conducted a detailed analysis of the MA fuel system (see paragraph 6.b.(3) below; Tab BB-2.12 to 2.14). Given that analysis, there is no evidence to suggest the fuel system or the other discrepancies listed above were factors in the mishap.

b. Inspections

(1) Mishap Aircraft

The last major inspection of the MA, a 1200-hour periodic inspection, occurred on 14 February 2014 without incident, and the next major inspection was not due for another 205.4 flying hours (Tab D-2). On 24 September 2014, maintenance personnel performed a 200-hour lower stabilator cable inspection. This is a recurring requirement to inspect cables and associated components for the horizontal tail flight control surfaces of the F-15. No defects were noted during this inspection (Tab DD-1, DD-2.7).

The day before the mishap, the MA flew three missions and the Mishap Aircraft Crew Chief (MC) accomplished a combined preflight/postflight inspection after the end of the day's flying (Tab D-3). This is a detailed flightline inspection conducted to assess airworthiness and mission readiness of the aircraft in preparation for the next day's flying.

On the day of the mishap, the MA flew three Code 1 missions prior to the mishap mission. The MC accomplished a preflight inspection in preparation for the MP's mission and noted no problems with the aircraft. (Tab D-3, V-3.4 to V-3.5).

(2) **Mishap Engines**

As of the start of that day's flying, the engine status was as follows (Tab D-2):

Engine	Type	Date Installed	Serial Number (S/N)	Operating Time (hrs)	Operating Cycles
#1 (left engine)	Pratt & Whitney F-100-PW-220	23 August 2013	PW-0E705279	7,802.7	373.9
#2 (right engine)	Pratt & Whitney F-100-PW-220	30 August 2012	PW-0E719131	10,494.4	736.1

Maintenance personnel accomplished a 200-hour periodic inspection on both engines on 6 August 2014 and identified no defects or discrepancies (Tab D-2, D-17 to D-20).

c. Maintenance Procedures

All aircraft forms and maintenance records show that maintenance was conducted IAW applicable Technical Orders (T.O.s) (Tab DD-1).

d. Maintenance Personnel and Supervision

A review of maintenance training records showed that all personnel who worked on the MA were fully qualified and appropriately experienced (Tab DD-1). There is no evidence that manning constraints or operational were factors in in the mishap.

e. Fuel, Hydraulic, Liquid Oxygen (LOX), and Oil Inspection Analyses

Samples from the fuel, LOX, oil, and hydraulic servicing equipment used on the MA were analyzed. Fuel, LOX, and oil analysis findings were normal. (Tab D-49 to D-52). Hydraulic fluid samples failed the standardized laboratory test for water content; however, the reported water content remained within limits specified for use in the F-15, T.O. 42B2-1-3, Table 4.1 (Tab D-50). Since the MA was destroyed on impact, post-mishap aircraft fluid samples were not available. There is no evidence that servicing equipment was a factor in this mishap.

f. Unscheduled Maintenance

Unscheduled maintenance is any maintenance action taken that is not the result of a scheduled inspection. Unscheduled maintenance is normally the result of a pilot-reported discrepancy during flight operations or a condition discovered by ground personnel during ground operations. There is no evidence to indicate that unscheduled maintenance was a factor in this mishap. (Tab DD-1, DD-2.1 to DD-2.34).

6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS

a. Structures and Systems

The forward and forward-center sections of the MA suffered heavy damage from ground impact and post-impact fire. The ailerons, flaps, rudders, and stabilator control surfaces were intact. All major pieces of the wreckage were collected and salvageable parts were sent for teardown analysis. Multiple components of the MA, including the Pitch/Roll Channel Assembly, Aileron Rudder Interconnect, and engine Digital Electronic Engine Control (DEEC) units were destroyed beyond testing capabilities. (Tab J-22, DD-1).

b. Evaluation and Analysis

(1) Engines

Boeing experts assessed the MA engines once they were returned to RAF Lakenheath (Tab J-5). They determined, based on engine tachometer indications, fan blade damage, and exhaust nozzle positions, that the #1 engine was operating at MILITARY power and the #2 engine at IDLE power at the time of impact (Tab J-16). These indications are consistent with the throttle positions commanded by the SRD and set by the MP during the spin (Tab V-1.18, HH-1).

HUD video analysis and MFLB testimony identified a faint brown smoke-trail briefly emanating from the MA's engines prior to the spin, bringing into question the potential of an engine problem (Tab R-36, HH-1). This smoke is normal when reducing power below afterburner and is consistent with MP's testimony of a power change at the same time (Tab V-1.6). Therefore, based on this evidence as well as the MP's testimony regarding normal ops checks throughout the mission, there is no evidence to suggest the engines were a factor in this mishap.

(2) Flight Controls

All MA primary flight controls were located and contained within the MA impact area (Tab J-16). Analysis of actuators and flight control components revealed they were operating normally (Tab J-16). In addition, Boeing engineers and the F-15 System Program Office (SPO) concluded all flight control positions were "in the expected range for an aircraft without pilot inputs" (Tab J-16, J-22).

All recovered flight control cables were sent to the Air Force Research Laboratory (AFRL) failure analysis lab at Wright-Patterson AFB. "The analysis provided by AFRL for the inspected cables showed the failures were due to a single event overload and not wear. This is consistent with failure due to ground impact as flight loads on cables are not high enough to cause overload without extensive wear." (Tab J-23).

Investigators removed panels from the MA and inspected all available flight control connections. All linkages and hardware were properly installed. Any observed damage was consistent with ground impact damage. (Tab J-23).

Based on crash site indications, technical analysis, and MP testimony, there is no evidence to suggest that any flight control anomalies were a factor in this mishap.

(3) Fuel System

The AIB used breakdown analysis of the MA fuel gauge, consultation with fuel gauge technicians, witness testimonies, and data link information from the MFLP's aircraft to determine aircraft fuel state and any potential fuel imbalances present at the time of the mishap.

The MA had approximately 5,400 lbs of fuel on board at impact, and both internal wing fuel tanks were balanced with approximately 450 lbs of fuel in each. Based on this analysis, there is no evidence to indicate any fuel system anomalies were a factor in this mishap. (Tab HH-2).

(4) Aircraft Radome

Nose Cap Condition: Mishap investigators discovered the first 8-10 inches of the aircraft radome in usable condition for analysis (Tab J-20). Figure 4 shows a close up of the tip of the MA's radome, which is protected by a metallic covering called a nose cap. F-15 SPO post-crash analysis assessed that there was a large gap between the radome body and nose cap, and that an excessive amount of sealant extruded from behind the nose cap (See Figure 4; Tab J-20, J-51). The sealant extruded up to 3/16 of an inch aft of the nose cap and created an uneven aerodynamic surface.

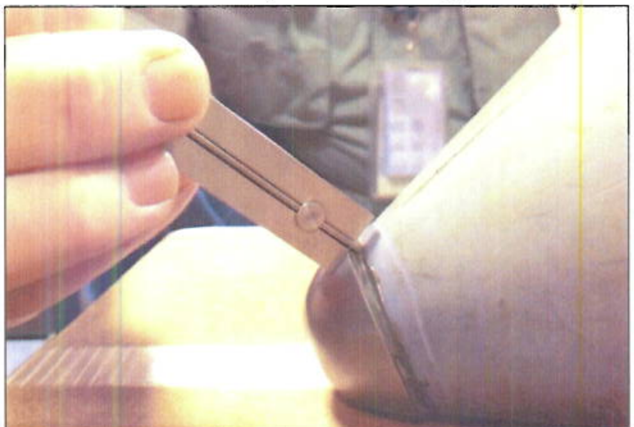

Figure 4: MA Radome

Nose Cap Impact on Flight Characteristics: According to the F-15 SPO: "A radome in this condition…is consistent with wind tunnel test data that would predict sufficient yaw to depart an aircraft and generate a high enough yaw rate to trigger the [SRD] as well as cause delayed spin recovery…" (Tab J-20). As discussed on page 6 of this report, the AFTTP 3-3.F-15 addresses this phenomenon, as does the F-15 Flight Manual. The Flight Manual states that the AOA levels at which radome imperfections can play a role (50-60 CPU) can be attained "momentarily during abrupt aft stick pulls at approximately 160-275 KCAS…" (Tab BB-2.15, BB-6.4). The Flight Manual goes on to state that if an aircraft experiences a nose-slice while at very high AOA, and other causal factors have been eliminated (lateral asymmetry, improper control inputs, etc.), then the radome may be suspect (Tab BB-2.15).

The yaw forces generated by radome imperfections are due to "asymmetric vortex shedding" (Tab J-19). Figure 5, adapted from a 2000 Atmospheric Flight Mechanics Conference paper, shows the asymmetric pressure differential experienced in these conditions (C_p stands for coefficient of pressure). The white area depicts negative pressure, or suction, naturally present due to airflows that start at the radome tip and radiate along the fuselage. (Tab JJ-1.5, JJ-1.11). When these airflows separate from the nose, a region of positive pressure develops (depicted by the reduced region of white on the left side of the picture). This zone, starting at the tip of the radome, can extend up to 11 feet along the side of the aircraft fuselage. This "zone of pressure differential" not only spreads along the side of the fuselage, but also acts like a 27-foot long lever from the aircraft's center of gravity (also referred to as a moment arm). As a result, this pressure differential can create extreme yaw forces

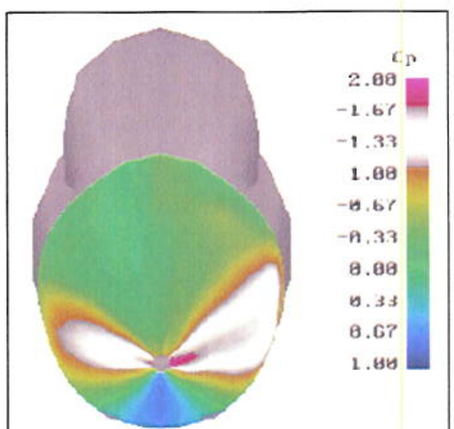

Figure 5: Pressure differential due to asymmetric vortex shedding

(Tab BB-6.4). While asymmetric vortex shedding will always happen at extreme AOA levels, radome imperfections lower the AOA at which this can occur to as low as 50 CPU (Tab BB-6.4).

The F-15 SPO analysis concluded that the MA's nose cap could have two impacts:

1. The aircraft would be more susceptible to departures at regions of AOA above 45 CPU due to extreme yawing moments generated by asymmetric vortex shedding.
2. The aircraft spin recovery would be delayed…" (Tab J-27).

Radome Configuration: The radome's nose assembly is comprised of the composite radome shell, a metallic nose plug that is seated into the tip of the radome (like a cork is seated in a bottle), and a metallic nose cap that fits over the entire assembly. The nose cap is secured to the nose plug and radome with sealant and a small screw installed at the apex of the nose (See Figure 6; Tab V-2.7, V-6.4, V-7.4). The F-15 SPO's breakdown analysis discovered that the nose plug was displaced by 3/32 of an inch from its proper seating in the radome. (See Figure 6; Tab J-55). The F-15 SPO concluded that at an unknown time, during nose cap removal, "the application of heat and/or blunt force necessary to remove the [nose cap] also caused the [nose plug] to pull…away from the [radome body]" (Tab J-55). This nose plug displacement can be seen in Figure 6 where there is silver metal showing between the red primer painted on both the radome body and nose plug. Normally, a nose cap should fit snugly over the nose plug-radome assembly; however, efforts to install the nose cap over the nose plug/radome assembly with this displacement created a large gap between the nose cap and radome (See Figure 7).

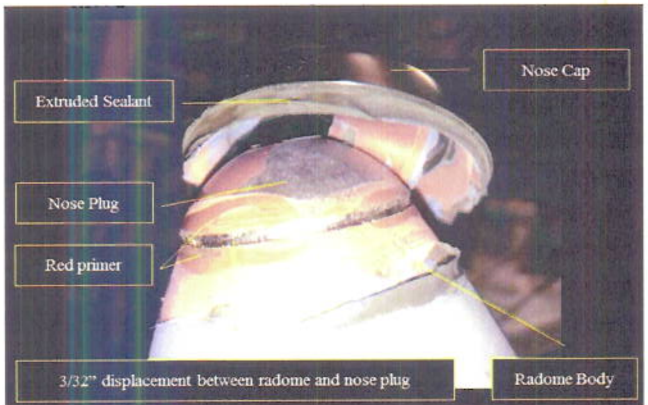

Figure 6: Nose Cap Removal and Nose Plug Displacement

The existence of this large gap between the nose cap and radome required a larger than normal amount of sealant in order to completely seal the nose cap in place. Some of this sealant filled in the 3/32 of an inch displacement between the radome and the nose plug (Tab J-55). The sealant that hardened in this space between the radome body and the nose plug is the primary evidence the nose cap was installed while the nose plug was still displaced from the radome (See Figure 8). This sealant formation also serves as evidence that this condition existed prior to the mishap and that the MA's impact with the ground did not somehow displace the nose plug. Otherwise, the

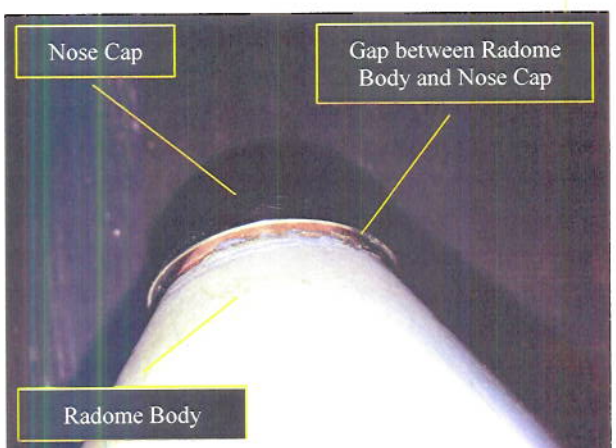

Figure 7: Gap Between Radome Body and Nose Cap after F-15 SPO Removed Sealant

sealant would not appear as it does in Figure 8, where it clearly filled and then hardened in the 3/32 of an inch space between the radome and nose plug.

Given the large amount of sealant required to seal the nose cap in place, some of that sealant extruded from underneath the nose cap (Tab J-20, J-51). Normally, this extruded sealant, also referred to as "squeeze out," is cleaned from the nose cap assembly (Tab V-2.7 to V-2.8, V-6.6, V-7.7). Post-mishap analysis, however, shows that efforts to clean or smooth this "squeeze out," were insufficient and left a larger than normal amount of extruded sealant beyond the aft edge of the nose cap (See Figure 4; Tab J-20, J-51).

Radome Maintenance History: According to MA records, the radome (S/N A1-1301) underwent depot overhaul in August 2011 and was installed on the aircraft on 23 September 2011 (Tab D-44 to D-47). The nose cap was replaced on 22 January 2014 during the MA's 400-hour periodic inspection (Tab DD-4.2). The AIB could not specifically determine when the nose plug became displaced from the radome body. However, it is most likely that the nose cap was installed over the nose plug in this displaced condition during the 22 January 2014 maintenance action. The technician who accomplished these repairs did not remember this particular maintenance action (Tab V-6.4 to V-6.5).

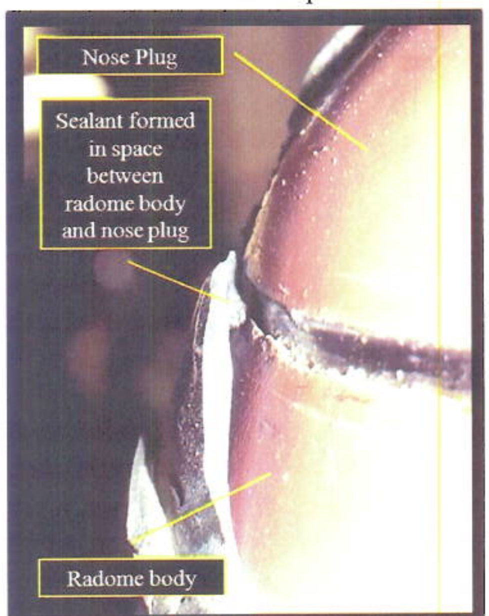

Figure 8: Sealant in Space Between Radome and Nose Plug

Maintenance records indicate that all actions performed on the nose cap were accomplished IAW tech data, inspected by qualified technicians, and received Quality Assurance review after the inspection was completed (Tab DD-3.1 to DD-3.4, DD-4.1 to DD-4.3).

The SPO and AIB surveyed F-15 T.O.s for information on nose cap maintenance standards and concluded there are "no references in the technical data that address the amount of sealant allowed under the radome nose cap." (Tab J-55). In other words, the guidance neither officially authorizes nor prohibits the sealant configuration found on the MA's radome. In fact, maintenance technician testimony revealed several different techniques for removing and/or smoothing excess sealant but did not identify specific requirements (Tab V-2.7 to V-2.8, V-6.6, V-7.7). Current guidance focuses only on nose cap alignment by comparing gap measurements between the nose cap and radome body at different locations around the circumference of the assembly (Tab J-51, J-55). The MA radome passed those inspections (Tab J-55).

7. WEATHER

a. Forecast Weather

The weather forecast at takeoff time was 8,000 meters visibility, light rain, scattered variable broken clouds at 1,500 feet, a broken layer of clouds at 7,500 feet, and winds out of the south at

15 knots gusting to 25 knots (Tab F-6). The forecast at landing time also included temporary conditions of 6,000 meters visibility, light rain due to thunderstorms, a broken layer of clouds at 1,500 feet (including cumulonimbus clouds), and a broken layer of clouds at 3,000 feet (Tab F-6). In the mission airspace, the weather forecast included isolated thunderstorms. Other forecast hazards included light mixed icing from 6,500 to 11,000 feet, and light rime icing from 11,000 to 18,000 feet (outside of thunderstorms) (Tab F-6).

b. Observed Weather

The observed weather was the same as was forecasted at RAF Lakenheath (Tab F-10). In the mission airspace, the MF searched and eventually found clear airspace suitable for training (Tab V-1.3 to V-1.4).

c. Space Environment

Not applicable.

d. Operations

The MF conducted their mission within prescribed operational weather limitations as prescribed by AFI 11-214, *Air Operations Rules and Procedures*.

8. CREW QUALIFICATIONS

a. Mishap Pilot

The MP was a current and qualified F-15 Wingman with 1,645 total hours and 223 hours in the F-15 (Tab G-7). At the time of the mishap, all necessary flight currencies were up-to-date and all required training for the planned mission was current IAW F-15 aircrew training manuals (Tab G-7 to G-29). The MP performed his last mission evaluation on 11 May 2014 and his last instrument/qualification evaluation on 6 September 2013 (Tab G-57). Evaluators rated the MP qualified on both evaluations (Tab G-57).

The MP's recent flight time was as follows (Tab G-4):

	Hours	Missions
Last 30 Days	18.9	15
Last 60 Days	39.4	29
Last 90 Days	61.2	44

b. Mishap Flight Lead Pilot

The MFLP was a current and qualified F-15 four-ship flight lead with 1,287 total hours and 684 hours in the F-15 (Tab G-30 to G-31). At the time of the mishap, all necessary flight currencies were up-to-date and all required training for the planned mission was current IAW F-15 aircrew training manuals (Tab G-32 to G-56). The MFLP performed his last mission evaluation on 24 April 2014 and his last instrument/qualification evaluation on 11 December 2013 (Tab G-75). Evaluators rated the MFLP qualified on both evaluations (Tab G-75).

The MFLP's recent flight time was as follows (Tab G-32):

	Hours	Missions
Last 30 Days	8.8	4
Last 60 Days	21.7	11
Last 90 Days	36.6	22

9. MEDICAL

a. Qualifications

At the time of the mishap, the MP and MFLP had current annual Preventative Health Assessments and were medically qualified for all flight and military duties without restriction. In addition, the MFLB was medically qualified for the incentive flight (Tab EE-1).

b. Health

The 48 MDG emergency room performed a thorough evaluation of the MP upon his return to base. Physical examination revealed minor injuries consistent with ejection and a parachute landing fall. Specifically, he had a sprained left ring finger, mild left calf cramping, and minor electrocardiogram (ECG) abnormalities. His injuries and ECG abnormalities fully resolved within three weeks, and he was medically returned to flight status. (Tab EE-1).

c. Toxicology

In accordance with AFI 91-204, *Safety Investigations and Reports,* medical personnel immediately conducted toxicology testing on the MP and maintenance personnel involved in the launch and flight of the MF. All blood and urine samples were submitted to the Armed Forces Medical Examiner System (AFMES) for toxicology analysis (Tab EE-1). These tests are used to identify carbon monoxide and ethanol levels in blood and to detect traces of drugs in the urine (Tab EE-1). AFMES toxicology testing confirmed no evidence of substance abuse (Tab EE-1).

Due to an oversight following witness interviews, toxicology labs for the MFLP and MFLB were not drawn. This oversight was not discovered until the Safety Investigation Board convened several days later, by which time toxicology testing was no longer accurate or useful (Tab R-10).

d. Lifestyle

According to the MP and MFLP's 72-hour and 14-day history, the MP and MFLP did not engage in any unusual habits, behaviors, or stressors that contributed to the accident (Tab EE-1). There were no lifestyle factors relevant to the mishap (Tab EE-1).

The MFLB did not complete a 72-hour and 14-day history since his mishap role was as a witness in the backseat, not aircrew (Tab R-10).

e. Crew Rest

AFI 11-202 *General Flight Rules*, Volume 3 requires aircrew observe "crew rest" prior to performing in-flight duties. Crew rest is a minimum 12-hour non-duty period before the flight duty period begins and must include the opportunity for at least 8 hours of uninterrupted sleep. This ensures aircrew are adequately rested before performing flight or flight-related duties.

According to the MP and MFLP's 72-hour and 14-day history, they complied with crew rest requirements (Tab EE-1).

10. OPERATIONS AND SUPERVISION

a. Operations

The 493 FS operations tempo at the time of the mishap was normal. The 493 FS had 33 assigned and attached pilots—of those, 23 were experienced pilots and of those, 16 were instructor pilots (Tab G-85). The MP was an inexperienced Wingman and the MFLP was an experienced Four-ship Flight lead at the time of the mishap (Tab G-85). AFI 11-2F-15, Volume 1 *F-15 Aircrew Training*, designates pilots as either "inexperienced" or "experienced" based on flying hours as a way to allocate limited resources, requiring more training events for inexperienced flight crew.

b. Supervision

The Top 3 authorized this mission (Tab K-4 to K-5). On the day of the mishap mission, the MP was trained and qualified to accomplish the assigned mission (Tab G-16, G-57, G-74, G-85). The squadron conducted a mass brief as part of the planned BFM surge and covered all relevant items, to include a discussion of out-of-control/departure recovery procedures (Tab K-14). There is no evidence to suggest operations or supervision were a factor in this mishap.

11. HUMAN FACTORS

a. Introduction

The AIB evaluated all human factors using the analysis and classification system established by the Department of Defense Human Factors Analysis and Classification System (DoD HFACS) guide, implemented by AFI 91-204, *Safety Investigations and Reports, Attachment 6,* dated 10 April 2014, to determine whether any human factors directly related to the mishap (Tab BB-1.1).

b. Applicable Factors

Procedural Guidance/Publications (OP003) is a factor when written direction, checklists, graphic depictions, tables, charts or other published guidance is inadequate, misleading or inappropriate and this creates an unsafe situation (Tab BB-1.31).

Post-mishap analysis revealed a larger than normal gap between the body of the radome, or aircraft nose, and the metallic cover for the tip of the radome, called a nose cap. The sealant used to secure the nose cap in place extruded from under the nose cap. This sealant extended aft of the nose cap on the radome body and formed an uneven aerodynamic surface. (Tab J-20, J-55). The SPO surveyed F-15 T.O.s for information on maintenance standards and concluded there are "no references in the technical data that address the amount of sealant allowed under the radome nose cap." In other words, the F-15 T.O. guidance neither officially authorizes nor prohibits the sealant configuration found on the MA's radome. (Tab J-55). In fact, maintenance technician testimony revealed several different techniques for removing and/or smoothing excess sealant but did not identify specific procedural guidance (Tab V-2.7 to V-2.8, V-6.6, V-7.7). Current guidance focuses only on nose cap alignment by comparing gap measurements between the nose cap and radome body at different locations around the circumference of the assembly (Tab J-51, J-55). The MA radome passed those inspections (Tab J-55).

Overcontrol/Undercontrol (AE104) is a factor when an individual responds inappropriately to conditions by either over controlling or under controlling the aircraft/vehicle/system. The error may be a result of preconditions or a temporary failure of coordination. (Tab BB-1.13).

After a series of two nose-low maneuvers, the MP executed an abrupt aft-stick pull (Tab S-2.2, V-1.6). An aft-stick pull at this point in the engagement is consistent with the last portion of a vertical jink where the defensive fighter attempts to generate closure with his opponent. Normally, however, this maneuver should be flown at the maximum performance limit of the aircraft to create the greatest possible challenge to the other aircraft (Tab BB-6.2, BB-6.3). This means that an F-15 pilot will use just enough aft-stick pressure to turn the aircraft optimally without stalling and without overshooting the desired AOA (Tab BB-6.2). Stalling the aircraft (as indicated by wing rock) results in poor turn performance and ineffective BFM maneuvering. Overshooting the desired AOA (i.e., "spiking" the AOA) can, under certain conditions, put the aircraft at an AOA level that increases the F-15's susceptibility to departure from controlled flight. (Tab BB-6.2).

In this case, however, the MP executed an abrupt aft stick pull that spiked the MA AOA to 54 CPU (Tab GG-1.3). Although the MP did not remember making this aft-stick pull, parametric data confirms a pitch change and rapid increase in AOA indicating an abrupt aft-stick movement (Tab V-1.14, GG-1.3). This abrupt aft-stick pull constituted an inappropriate response to conditions and over controlled the aircraft.

12. GOVERNING DIRECTIVES AND PUBLICATIONS

a. Publically Available Directives and Publications Relevant to the Mishap

(1) AFI 51-503, *Aerospace Accident Investigations*, 26 May 2010
(2) AFI 91-204, *Safety Investigations and Reports*, 10 April 2014
(3) AFI 11-202, Volume 1, *Aircrew Training*, 22 November 2010
(4) AFI 11-202, Volume 1, *Aircrew Training*, 25 July 2011
(5) AFI 11-202, Volume 2, *Aircrew Standardization/Evaluation Program*, 22 November 2010

(6) AFI 11-202, Volume 2, *Aircrew Standardization/Evaluation Program*, United States Air Forces in Europe Supplement , 11 July 2011
(7) AFI 11-202, Volume 2, *Aircrew Standardization/Evaluation Program*, RAF Lakenheath Supplement , 11 July 2012
(8) AFI 11-202, Volume 3, *General Flight Rules*, 7 November 2014
(9) AFI 11-202, Volume 3, *General Flight Rules*, United States Air Forces in Europe Supplement , 19 March 2012
(10) AFI 11-301, Volume 1, *Aircrew Flight Equipment (AFE) Program*, 22 February 2009, IC 1 2 May 2014
(11) AFI 11-301, Volume 1, *Aircrew Flight Equipment (AFE) Program*, United States Air Forces in Europe Supplement, 22 September 2009
(12) AFI 11-401, *Aviation Management*, 10 December 2011
(13) AFI 11-401, *Aviation Management*, United States Air Forces in Europe Supplement, 28 November 2011
(14) AFI 11-401, *Aviation Management*, RAF Lakenheath Supplement, 29 April 2014
(15) AFI 11-418, *Operations Supervision*, 15 September 2011, Change 1, 1 March 2013
(16) AFI 11-418, *Operations Supervision*, RAF Lakenheath Supplement, 14 June 2012
(17) AFI 11-2F-15V1, *F-15 Aircrew Training*, 7 September 2010
(18) AFI 11-2F-15V1, *F-15 Aircrew Training*, United States Air Forces in Europe Supplement, 25 July 2011
(19) AFI 11-2F-15, Volume 2, *F-15--AIRCREW EVALUATION CRITERIA*, 14 July 2011
(20) AFI 11-2F-15, Volume 3, *F-15--Operations Procedures*, 18 September 2014
(21) Lakenheath Instruction 11-2F-15-E, Volume 3, *Local Operating Procedures*, Change 1, 24 January 2012
(22) AFI 48-123, *Medical Examinations and Standards*, 31 Oct 2014
(23) AFMAN 91-223, *Aviation Safety Investigations and Reports*, 16 May 2013

NOTICE: All directives and publications listed above are available digitally on the Air Force Departmental Publishing Office website at: http://www.e-publishing.af.mil.

b. Other Directives and Publications Relevant to the Mishap

(1) TO 1F-15A-1, *Flight Manual USAF Series F-15A/B/C/D AIRCRAFT BLOCK 7 and up, ISS-6*, 15 January 2014
(2) TO 1F-15A-1CL-1, *Flight Crew Checklist USAF Series F-15A/B/C/D AIRCRAFT BLOCK 7 and up*, Change 6, 15 January 2014
(3) TO 1F-15A-6, *Inspection and Maintenance Requirements Manual*, 15 March 2014
(4) TO 1F-15C-00GV-00-1, *Aircraft Description and Maintenance Orientation*, 15 January 2014
(5) TO 1F-15C-2-28GS-00-1, *General System Fuel System*, 15 April 2014
(6) TO 1F-15C-2-27GS-00-1, *Flight Control Systems USAF Series F-15C/D Aircraft*, 1 January 2014
(7) TO 1F-15C-2-28JG-21-1, *Fuel System - Distribution Internal Transfer*, 15 October 2012
(8) TO 1F-15C-3-5, *Structural Repair Organizational and Intermediate Typical Repairs, Repairs of Special Structure, and Sealing*, 1 March 2014

(9) TO 1F-15A-6, *Inspection and Maintenance Requirements Manual*, 15 March 2014
(10) TO 1F-15A-6WC-1, *Combined Preflight/Postflight Inspection USAF Series F-15A/B/C/D Aircraft*, 15 March 2014
(11) 13A5-56-11, *ACES II Ejection Seat*, 6 January 2014
(12) AFTTP 3-3, *AFTTP 3-3.F-15, Combat aircraft Fundamentals--F-15*, 18 May 2012
(13) AHC-2, *Aircraft Handling Characteristics 2*, 1 November 2013
(14) Silver Bullet LF05-052, *High Angle of Attack Operation of the F-15A-D With and Without External Tanks*, 15 June 2005
(15) McDonnell Douglas Aerospace Final Report, *Aerodynamic Evaluation of F-15 Nose Radome*, Final Report, 31 July 1997
(16) TO 1T-6A-1, *Flight Manual USAF/USN Series T-6A Aircraft*, Ch 7, 1 December 2012
(17) AIAA 2000-41-4, Forebody Aerodynamic Asymmetry on a Full-Scale F-15 Radome, 14-17 August 2000

c. Known or Suspected Deviations from Directives or Publications

Not applicable.

13. NEWS MEDIA INVOLVEMENT

News media involvement following the mishap was moderate and short lived, with reports primarily in the UK and the Lincolnshire district. 48 FW Public Affairs (PA) issued a press release on the wing's official website and submitted updates through social media. The 48 FW/CC and a representative from PA participated in several live interviews with local news affiliates on the evening of the mishap and the following day. The media coverage of the mishap was generally neutral to slightly positive in character. (Tab FF-1 to FF-5).

14. ADDITIONAL AREAS OF CONCERN

Not applicable.

03 December 2014 [redacted] Colonel, USAF
President, Accident Investigation Board

STATEMENT OF OPINION

F-15D, T/N 86-0182
NEAR SPALDING, LINCOLNSHIRE, UNITED KINGDOM
8 OCTOBER 2014

Under 10 U.S.C. § 2254(d) the opinion of the accident investigator as to the cause of, or the factors contributing to, the accident set forth in the accident investigation report, if any, may not be considered as evidence in any civil or criminal proceeding arising from the accident, nor may such information be considered an admission of liability of the United States or by any person referred to in those conclusions or statements.

1. OPINION SUMMARY

I find, by clear and convincing evidence, that the mishap was caused by a combination of two factors. First, the mishap pilot's (MP) abrupt aft-stick pull placed the mishap aircraft (MA) in an extreme angle of attack (AOA) flight regime. Second, while in that aerodynamic regime, imperfections on the radome's nose-cap assembly generated sufficient yaw forces for a spin entry and delayed spin recovery beyond the minimum uncontrolled bailout altitude. By a preponderance of evidence, I also find that the inherent reduced stability of the two seat F-15D model, as compared to the single-seat F-15C, was a significant contributing factor to the mishap.

On 8 October 2014, at 15:26 hours local time, an F-15D aircraft, tail number (T/N) 86-0182, assigned to the 493d Fighter Squadron, 48th Fighter Wing, RAF Lakenheath, entered into a spin and crashed while conducting a basic fighter maneuvers (BFM) training mission in East Anglia airspace north of RAF Lakenheath. During the mission's final planned engagement, the MP maneuvered the MA into a series of descending vertical maneuvers. At 15,200 feet mean sea level (MSL), the MP executed an abrupt aft-stick pull that spiked the MA's AOA. The MA then experienced an uncommanded nose-slice to the left, constituting a loss of aircraft control. The MA entered a flat spin, reaching a peak yaw rate of 111° per second at approximately 12,200 feet MSL. The MP attempted to regain control by following MA Spin Recovery Display commands.

During the spin, the mishap flight lead pilot (MFLP) supported by calling out MA altitudes to maintain the MP's situational awareness. The MP testified that the MFLP's "7,000" call was the point at which he turned his attention to bailout procedures. After passing 6,000 feet above ground level, the MP correctly abandoned spin recovery attempts and prepared for bailout. The MP ejected from the aircraft at 5,450 feet MSL and sustained minor injuries. There were no civilian injuries or fatalities. The MA was destroyed upon impact, at an estimated cost of $44,608,743.00. Private property damage included fire and impact damage to a farmer's field, with an estimated environmental clean-up cost of $604,405.25.

I developed my opinion by analyzing factual data from historical records, Air Force directives and guidance, engineering analysis, witness testimony, and information provided by technical experts. The MA's removable memory module (RMM) was recovered from the crash site and provided parametric data (e.g., roll, pitch, yaw, etc.) that enabled extensive review of Heads Up

Display (HUD) video, flight data, flight simulations, and animated simulations. However, since the F-15 does not have a flight data recorder that records actual flight control positions, I was constrained in my ability to assess the MP's spin recovery efforts with precision.

2. CAUSE

At the end of a series of two nose-low vertical maneuvers (a BFM tactic known as "vertical jinks") the MP executed an abrupt aft-stick pull while descending through 15,200 feet MSL. The MA nose rose 20°, the HUD display spiked at 45 cockpit units (CPU—an F-15-specific measure of AOA), and the MA entered wing rock indicating it was stalled. RMM data showed the MA's AOA peaked at 54 CPU.

Although the MP testified he did not remember this move, parametric data analysis confirmed AOA and pitch changes consistent with an abrupt aft-stick pull. Such a maneuver is consistent with an attempt to fly the last portion of a vertical jink, where the defensive fighter attempts to generate closure with his opponent. Normally, however, this maneuver is flown at the maximum performance limit of the aircraft. This means that an F-15 pilot will command just enough aft-stick pressure to both raise the nose of the aircraft without wing rock and achieve a rapid AOA onset rate without overshooting, or spiking, the AOA. In this case, the MP's aft-stick pull was excessive, resulted in wing rock, and spiked the MA's AOA. At the end of this maneuver, the MA's nose aggressively sliced to the left, an indication of a departure from controlled flight. The F-15 Flight Manual states: "If a nose slice is experienced while at very high AOA…and other causal factors have been eliminated (lateral asymmetry, improper controls inputs, etc.) then the radome may be suspect."

I assessed four potential causal factors based on this and other guidance on F-15 flight characteristics: lateral asymmetry and/or aircraft system problems, improper flight control inputs, increased susceptibility to departure inherent in two-seat F-15D aircraft as compared to the single-seat F-15C, and the role of radome imperfections at high AOA.

First, after reviewing post-mishap technical assessments, interviewing technical experts, and reviewing all maintenance documentation, I ruled out lateral asymmetry as a cause of the aircraft spin. In addition, there was no evidence of aircraft system malfunctions (flight controls, engines, or otherwise) that could have been a casual factors in this mishap.

Second, regarding improper flight control input, the MA's HUD video and parametric data indicate the MP's execution of the aft-stick pull was purely along the longitudinal axis (i.e., fore-aft stick position) and there were no rudder inputs during the move. Any residual lateral stick or rudder inputs during this maneuver (the Flight Manual definition of "improper control inputs") would have generated yaw, sideslip, or bank angle changes not evident in the MA's parametric data during the aft-stick pull.

The third factor I assessed was the fact that the MA was an F-15D model. The F-15 Flight Manual states that two-seat F-15s exhibited a significant decrease in yaw stability during early flight-testing, as compared to the single-seat F-15C, and especially during rapid onset of AOA at low or IDLE power settings. Although the MA's power setting was higher than these levels, parametric data indicates the MP's abrupt aft-stick pull was sufficient to spike the AOA into a regime of increased susceptibility to departure from controlled flight. Therefore, I conclude by a preponderance of evidence that the reduced F-15D stability is a significant contributing factor in this mishap. However, the aggressiveness of the nose slice and swift transition to a sustained flat, erect spin point to the radome, the fourth factor, as the chief causal suspect in this mishap.

Analysis of the first 8-10 inches of MA radome, discovered intact at the crash site, revealed there was a large gap between the radome body and the nose cap. At an undetermined time prior to the mishap, the nose plug of the radome became displaced from the radome's composite shell by 3/32 of an inch. The last recorded radome maintenance was accomplished on 22 January 2014, at which time the maintenance technician likely installed the nose cap over the radome and nose plug in this condition. As a result, a larger than normal amount of sealant was required to properly seal the nose cap in place. Some of this sealant extruded from underneath the nose cap, was insufficiently cleaned from the radome surface, and created an uneven aerodynamic surface.

A survey of maintenance guidance revealed no specifications regarding the amount of sealant allowed under the radome nose cap. In other words, F-15 technical orders neither authorize nor prohibit the sealant configuration found on the MA's radome. In fact, maintenance technician testimony revealed different techniques for removing and/or smoothing excess sealant but did not identify specific requirements. Rather, current guidance focuses on nose cap alignment by comparing gap measurements between the nose cap and radome body at different locations around the circumference of the assembly. The MA radome passed those inspections.

Nevertheless, a series of aerodynamic studies have shown that similar radome imperfections are capable of generating yaw forces that can induce a spin and delay spin recovery at very high AOA levels. Per the Flight Manual, these AOA levels (50-60 CPU) can be attained "momentarily during abrupt aft stick pulls at approximately 160-275 [Knots Calibrated Airspeed]…" These radome imperfections do not significantly affect aircraft performance except in infrequent cases where a pilot commands extreme AOA at certain airspeeds. In this case, the MP commanded an extreme AOA reaching a peak of 54 CPU. These conditions enabled the radome imperfections to generate yaw forces causing the MA to spin and delaying recovery beyond the prescribed bailout altitude for an uncontrolled aircraft.

3. CONCLUSION

I find, by clear and convincing evidence, that the mishap was caused by a combination of two factors. First, the MP's abrupt aft-stick pull placed the MA in an extreme AOA flight regime. Second, while in that aerodynamic regime, imperfections on the radome's nose cap assembly generated sufficient yaw forces for a spin entry and delayed spin recovery beyond the minimum uncontrolled bailout altitude. By a preponderance of evidence, I also find that the inherent reduced stability of the F-15D model was a significant contributing factor to the mishap.

03 December 2014

[redacted] Col, USAF
President, Accident Investigation Board