UNITED STATES AIR FORCE AIRCRAFT ACCIDENT INVESTIGATION BOARD REPORT

F-16C, T/N 88-0433

421st FIGHTER SQUADRON
388th FIGHTER WING
HILL AIR FORCE BASE, UTAH

LOCATION: UTAH TEST AND TRAINING RANGE, UTAH

DATE OF ACCIDENT: 4 MAY 2012

BOARD PRESIDENT: LIEUTENANT COLONEL THOMAS R. OLSEN, JR.

CONDUCTED IAW AIR FORCE INSTRUCTION 51-503

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR COMBAT COMMAND
JOINT BASE LANGLEY-EUSTIS VA

OFFICE OF THE VICE COMMANDER
205 DODD BOULEVARD SUITE 203
JOINT BASE LANGLEY-EUSTIS VA 23665-2788

24 AUG 2012

ACTION OF THE CONVENING AUTHORITY

The Report of the Accident Investigation Board, conducted under the provisions of AFI 51-503, that investigated the 4 May 2012 mishap near Hill AFB, UT, involving F-16C, T/N 88-0433, assigned to the 388 FW, Hill AFB, UT, complies with applicable regulatory and statutory guidance and on that basis is approved.

FOR:

WILLIAM J. REW
Lieutenant General, USAF
Vice Commander

Agile Combat Power

EXECUTIVE SUMMARY

AIRCRAFT ACCIDENT INVESTIGATION

F-16C, T/N 88-0433
Utah Test and Training Range (Near Hill AFB, UT)
4 May 2012

On 4 May 2012, at approximately 08:30 hours local time (L), an F-16C, tail number 88-0433, assigned to the 421st Fighter Squadron, 388th Fighter Wing (388 FW), Hill Air Force Base (AFB), Utah, crashed in the northern portion of the Utah Test and Training Range (UTTR), approximately 50 nautical miles west of Hill AFB. No military or civilian personnel were injured in the mishap. The mishap aircraft (MA) was destroyed on impact, with no damage to private property. Mishap damage costs were $23,869,281.

The mishap pilot (MP) was conducting close air support training as the second aircraft in a two-ship formation, when he reported an engine failure. Immediately following indications of a compressor stall and engine failure, the MP maneuvered west to avoid mountainous terrain and the Great Salt Lake. He correctly applied all critical action procedures and coordinated with his mission flight lead to initiate search and rescue operations.

Due to low altitude at engine failure, recovery to any runway was impossible, regardless of pilot action. After several unsuccessful attempts to restart the engine, the MP placed the MA in a stable, climbing attitude. The MP safely ejected approximately one and a half minutes after the initial compressor stall indication. UTTR emergency response crews and a local Life Flight helicopter recovered the MP.

The Board President found, by clear and convincing evidence, the cause of the mishap was failure of the number 17 blade in the first stage fan section of the engine. The fan blade liberated from its supporting structure, causing catastrophic damage to the rest of the fan, compressor, and high and low pressure turbines. Because of this extensive damage, the engine could not produce thrust or be restarted.

Additionally, the Board President found, by a preponderance of the evidence, a blade anomaly coupled with eight years of normal operating fatigue substantially contributed to the mishap. The anomaly at the base of blade 17 was formed during a manufacturing process. Blade 17 separated due to fatigue cracking propagating from the edge of the anomaly.

The Board President also found, by a preponderance of the evidence, the failure to detect the anomaly during the installation inspection process in 2004 substantially contributed to the mishap.

Under 10 U.S.C. 2254(d), any opinion of the accident investigators 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.

SUMMARY OF FACTS AND STATEMENT OF OPINION
F-16C, T/N 88-0433
4 May 2012

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COMMONLY USED ACRONYMS AND ABBREVIATIONS

388 FW	388th Fighter Wing
421 FS	421st Fighter Squadron
466 FS	466th Fighter Squadron
ACC	Air Combat Command
ACES	Advanced Concept Ejection Seat
AF	Air Force
AFB	Air Force Base
AFE	Aircrew Flight Equipment
AFI	Air Force Instruction
AFTO	Air Force Technical Order
AGL	Above Ground Level
AIB	Aircraft Investigation Board
ATV	All Terrain Vehicle
BPO/PR	Basic Post-Flight/Pre-Flight
CAS	Close Air Support
CP	Command Post
CSFDR	Crash Survivable Flight Data Recorder
CSMU	Crash Survivable Memory Unit
EPU	Emergency Power Unit
FTIT	Fan Turbine Inlet Temperature
HAG	Helicopter Air-to-Ground
HPO	Hourly Post-Flight Inspection
HPT	High Pressure Turbine
HUD	Heads up Display
IAW	In Accordance With
IGV	Inlet Guide Vanes
IMDS	Integrated Maintenance Data System
IP	Instructor Pilot
JFS	Jet Fuel Starter
JTAC	Joint Terminal Attack Controller
K	Thousand
KIAS	Knots Indicated Airspeed
L	Local Time
LA	Legal Advisor
LPT	Low Pressure Turbine
LRU	Line Replaceable Unit
MA	Mishap Aircraft
ME	Mishap Engine
MFL	Maintenance Fault List (when referenced to maintenance data)
MFL	Mishap Flight Lead
MH	Magnetic Heading
MM	Medical Member
MP	Mishap Pilot
MS	Mishap Sortie
MSL	Mean Sea Level
MXM	Maintenance Member
nm	Nautical Miles
NOTAMS	Notices to Airmen
ORE	Operational Readiness Exercise
PM	Pilot Member
psi	Pounds Per Square Inch
REC	Recorder
ROK	Republic of Korea
RPM	Revolutions Per Minute
SOF	Supervisor of Flying
SRU	Shop Replaceable Unit
TAC	Total Accumulated Cycles
TCI	Time Change Inspection
TCTO	Time Compliance Technical Order
TDY	Temporary Duty
T/N	Tail Number
TO	Technical Order
UT	Utah
UTTR	Utah Test and Training Range
W&B	Weight and Balance

The above list was compiled from the Summary of Facts, the Statement of Opinion, the Index of Tabs, and Witness Testimony (Tab V).

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 4 June 2012, Lieutenant General William J. Rew, Vice Commander, Air Combat Command (ACC), appointed Lieutenant Colonel Thomas R. Olsen, Jr. to conduct an accident investigation under Air Force Instruction (AFI) 51-503, *Aerospace Accident Investigations.* The Accident Investigation Board (AIB) investigated the 4 May 2012 mishap of an F-16C aircraft, tail number (T/N) 88-0433, in the northern portion of the Utah Test and Training Range (UTTR) near Hill Air Force Base (AFB). The investigation was conducted at Hill AFB, Utah, from 19 June 2012 to 10 July 2012. The following board members were appointed: a medical member (MM), a pilot member (PM), a legal advisor (LA), a maintenance member (MXM), and a recorder (REC). (Tabs Y-3 through Y-4)

b. Purpose

This is a legal investigation convened to inquire into the facts surrounding the aircraft or aerospace 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 4 May 2012 at approximately 08:27 local time (L), the Mishap Aircraft (MA) experienced engine failure one hour after takeoff, during a Close Air Support (CAS) training mission. After approximately 90 seconds of failed engine re-starts, the Mishap Pilot (MP) ejected safely. (Figure 1 and Tabs J-2 and J-8 through J-11) The MA impacted the ground in the UTTR approximately 50-55 nautical miles (nm) west of Hill AFB. (Tab J-2) The MA was destroyed upon impact with a loss valued at $23,869,281.00. No military or civilian personnel were injured, and no civilian property was damaged. (Tabs P-4 and P-6)

3. BACKGROUND

The 388th Fighter Wing (388 FW) stationed at Hill AFB, Utah, delivers combat capability to deploy, employ, and sustain F-16s worldwide. The 421st Fighter Squadron (421 FS) is a component of the 388 FW. The wing and its subordinate units are all components of the Air Force's Air Combat Command. (Tabs CC-3 through CC-17)

a. Air Combat Command

ACC is the primary force provider of combat airpower to America's warfighting commands. To support the global implementation of national security strategy, ACC operates fighter, bomber, reconnaissance, battle-management, and electronic-combat aircraft. It also provides command, control, communications and intelligence systems, and conducts global information operations.

As a force provider, ACC organizes, trains, equips, and maintains combat-ready forces for rapid deployment and employment while ensuring strategic air defense forces are ready to meet the challenges of peacetime air sovereignty and wartime air defense. ACC numbered air forces provide the air component to U.S. Central, Southern, and Northern Commands. ACC also augments forces to U.S. European, Pacific and Strategic Command. (Tabs CC-3 through CC-6)

b. Unit Information

(1) Twelfth Air Force (Air Forces Southern)

Twelfth Air Force serves as a primary conventional fighter and bomber warfighting headquarters trained and ready for worldwide employment of airpower. It is responsible for the combat readiness of 10 active-duty wings and one direct reporting unit. These subordinate commands operate more than 731 combat aircraft with more than 66,400 uniformed and civilian Airmen. The command is also responsible for the operational readiness of 18 Twelfth Air Force-gained wings and other units of the Air Force Reserve and Air National Guard in the western and midwestern United States. (Tabs CC-7 through CC-8)

(2) 388th Fighter Wing

The 388th Fighter Wing delivers combat capability to deploy, employ, and sustain F-16s worldwide to Fly, Fight, and Win any conflict. With more than 2,000 military and civil service professionals, the wing consists of eight squadrons which maintain and operate 48 primary assigned F-16C aircraft and maintain the Utah Test and Training Range. The 388 FW's motto is, "America's Airmen defending our nation at home and abroad...Liberty or Death!" (Tabs CC-9 through CC-11)

(3) 421st Fighter Squadron

The 421st Fighter Squadron, one of two fighter squadrons assigned to the 388 FW, flies the Lockheed Martin F-16C Fighting Falcon. As part of the world's largest Block 40 Common Configuration Improvement Program F-16C wing, the 421 FS conducts flying operations to maintain combat readiness of a 24-aircraft F-16C squadron.

It prepares to deploy worldwide to conduct day/night air superiority and precision strike sorties employing laser-guided and inertially-aided munitions during contingencies and combat operations. Equipped with night vision goggles and the Advanced Targeting Pod, the 421 FS continues its proud combat heritage as a premier night fighter squadron. (Tabs CC-12 through CC-14)

c. F-16C Fighting Falcon

The F-16C Fighting Falcon is a compact, multi-role fighter aircraft. It is highly maneuverable and has proven itself in air-to-air combat and air-to-surface attack. It provides a relatively low-cost, high-performance weapon system for the United States and allied nations.

In an air combat role, the F-16C's maneuverability and combat radius (distance it can fly to enter air combat, stay, fight and return) exceed that of all potential threat fighter aircraft. It can locate targets in all weather conditions and detect low flying aircraft in radar ground clutter. In an air-to-surface role, the F-16C can fly more than 500 miles (860 kilometers), deliver its weapons with superior accuracy, defend itself against enemy aircraft, and return to its starting point. An all-weather capability allows it to accurately deliver ordnance during non-visual bombing conditions. (Tabs CC-15 through CC-17)

4. SEQUENCE OF EVENTS

a. Mission

The mishap sortie (MS) was scheduled and briefed as a CAS mission during an operational readiness exercise (ORE). The MP was number two of a two-ship formation of F-16Cs with callsigns Troll 11 and Troll 12. Troll flight was working with a joint terminal attack controller (JTAC) on the ground. The MS was flown over the helicopter air-to-ground (HAG) range located in the UTTR, approximately 50 nm west of Hill AFB. (Tabs S-2, V-1.8, V-4.6 through V-4.9, and Z-9)

b. Planning

The pilot originally scheduled to fly as Troll 12 was ill and the MP was chosen as a replacement, as he was already working non-flying duties that day. The MP had the proper crew rest, currency, and qualifications to fly the mission. The mission materials for the mishap flight lead (MFL) and MP were prepared by the mission planning cell and were provided at the mission brief. (Tabs V-4.4 through V-4.6, V-6.3 through V-6.4)

Two days prior to the mishap, all of the participating pilots, including the MP, attended standard briefings related to ORE missions. This was accomplished to save time during the ORE flying days due to the number of missions and the limited 12-hour pilot workday. On the day of the mishap, the MFL briefed the remaining required items pertaining to that day's missions. The operations supervisor (Top 3) briefed the MFL and MP on the weather, notices to airmen (NOTAMs), and ORE specific information. (Tabs V-4.5 and V-4.7) The NOTAMs at the time of the mishap did not affect operations. (Tabs AA-3 through AA-15) All applicable mission briefings and planning were accomplished.

c. Preflight

The MFL and MP left the squadron for the aircraft at approximately 06:10L. Both wore the standard life support gear and a survival vest for ORE simulation of a combat environment. The MP accomplished pre-flight inspections in accordance with (IAW) applicable checklists. Ground and taxi operations were uneventful. (Tabs V-3.8 through V-3.10, and V-3.15)

d. Summary of Accident

Troll 11 (MFL) and Troll 12 (MP) took off at approximately 07:20L from Hill AFB. Departure and entrance into the UTTR airspace was uneventful. Troll 11 checked in with the JTAC at 07:38L to start the mission. (Tabs K-4, V-1.8 and V-4.8)

The crash survivable flight data recorder (CSFDR) showed normal aircraft operation until 08:27:55L, when the engine fan speed (N1) and core speed (N2) began to drop without a corresponding decrease in throttle from the MP. (Tab J-8 through J-11) The MP's heads up display (HUD) video simultaneously shuddered due to the force of the engine malfunction. (Tab Z-5) The MP heard a single bang at this time and felt a substantial deceleration of the MA, enough to force his weight forward into his shoulder harness. The flight instruments indicated that the engine revolutions per minute (RPM), representing engine core speed, rapidly decreased. (Tabs V-3.12 and V-3.13)

At 08:27:57L, the CSFDR recorded an ENG 020 MFL COMPRESSOR STALL, indicating an engine stall. (Tabs J-8 and V-8.8) The fan speed decreased rapidly from 95% to 15% in 0.6 seconds. (Tabs J-31 and V-8.9) Engine core speed decreased from approximately 96% to sub-idle and fan turbine inlet temperature (FTIT) started increasing, indicating engine failure and increasing engine temperature. The CSFDR recorded the following maintenance fault lists (MFL) over the next 11 seconds. (Tabs J-9, J-14 and V-8.7 through V-8.8):

08:27:59L – ENG 009 MFL T4B OVERTEMP – engine over temperature (Tab V-8.8)
08:27:59L – ENG 017 PFL ENG MACH FAIL – engine is in hybrid mode (Tab V-8.9)
08:27:59L – ENG 023 MFL HYBRID MODE XFER – engine transfer to hybrid (Tab V-8.10)
08:28:05L – ENG 068 MFL T4B TEMP SIGNAL FAIL –sensor failure (Tab V-8.11)
08:28:08L – ENG 058 MFL FLAMEOUT SUB-IDLE – engine below idle (Tab V-8.11)

All fault recordings indicated an engine stall and rapid loss of thrust. (Tabs V-8.8 through V-8.11) At the time of the stall, the MP's HUD showed the MA at 9,780 feet (ft) mean sea level (MSL) / 5,510 ft above ground level (AGL), 301 knots indicated airspeed (KIAS), 360 degrees magnetic heading (MH), approximately 60 degrees of right bank and 2 degrees nose low. (Tab Z-5) Three seconds after the stall, the MP communicated his emergency to the MFL. (Tabs J-8 through J-11 and N-2)

At 08:28:09L, the MP jettisoned two 370-gallon fuel tanks to lighten the MA. (Tabs K-26 and J-9) This action increased the MA's glide distance and time before ground collision. The tanks impacted an uninhabited part of the range. (Tab S-2) The MP's HUD stopped recording 1 second after jettison. At this point, the MA was at 8,920 ft MSL, 289 KIAS, 319 degrees MH, approximately 5 degrees of left bank and 4 degrees descent. (Tab Z-6)

At 08:28:11L, the MAIN GEN FAIL light came on indicating the main power generator was not providing power to the MA. (Tabs J-9 and V-8.12) This caused the emergency power unit (EPU) to activate as designed. The EPU supplies limited power to the flight controls in the event of either electrical or hydraulic failure, often linked to an engine failure. The EPU does not provide any thrust. (Tabs J-12, V-4.9 through V-4.12, and V-8.12 through V-8.13)

At approximately 08:28:13L, the MP radioed “2 just lost the motor, heading out west towards Eagle.” (Tab N-2) Eagle range is a flat area surrounded by a dry lakebed, about 10 miles west of the MA’s location. (Figure 2) At 08:28:18L, the MP initiated engine restart attempts by selecting a secondary (“SEC”) engine mode and 4 seconds later, returning to the primary (“PRI”) engine mode. (Tabs J-9 and J-10) At 08:28:35L, the MP selected START 2 to turn on the jet fuel starter (JFS). (Tab J-10) All MP responses were IAW the emergency checklist to restart the engine. (Tabs G-29, and V-3.13 through V-3.15)

At 08:28:41L, the MFL asked “have you attempted a restart?” The MP replied “affirm, second restart now, looks like it’s not going anywhere. I felt a pretty big bang.” (Tab N-2)

From 08:28:55L to 08:29:09L, the MP attempted two more engine restarts by selecting SEC then PRI, but still had no thrust. (Tab J-10 and V-8.15) The engine did not respond and at 08:29:12L the MP radioed “passing 6000 [MSL] now, motor’s still at 30% [RPM], I’m getting out [indicating ejection].” (Tabs J-11 and N-2) The canopy warning light activated at 08:29:31L, indicating ejection. (Tab J-11) The MA was over 49 nm from any airfield at the time of ejection and could not reach any runway surface. (Tab Z-9) Figure 1 shows the timeline of the mishap with MA indications and MP actions.

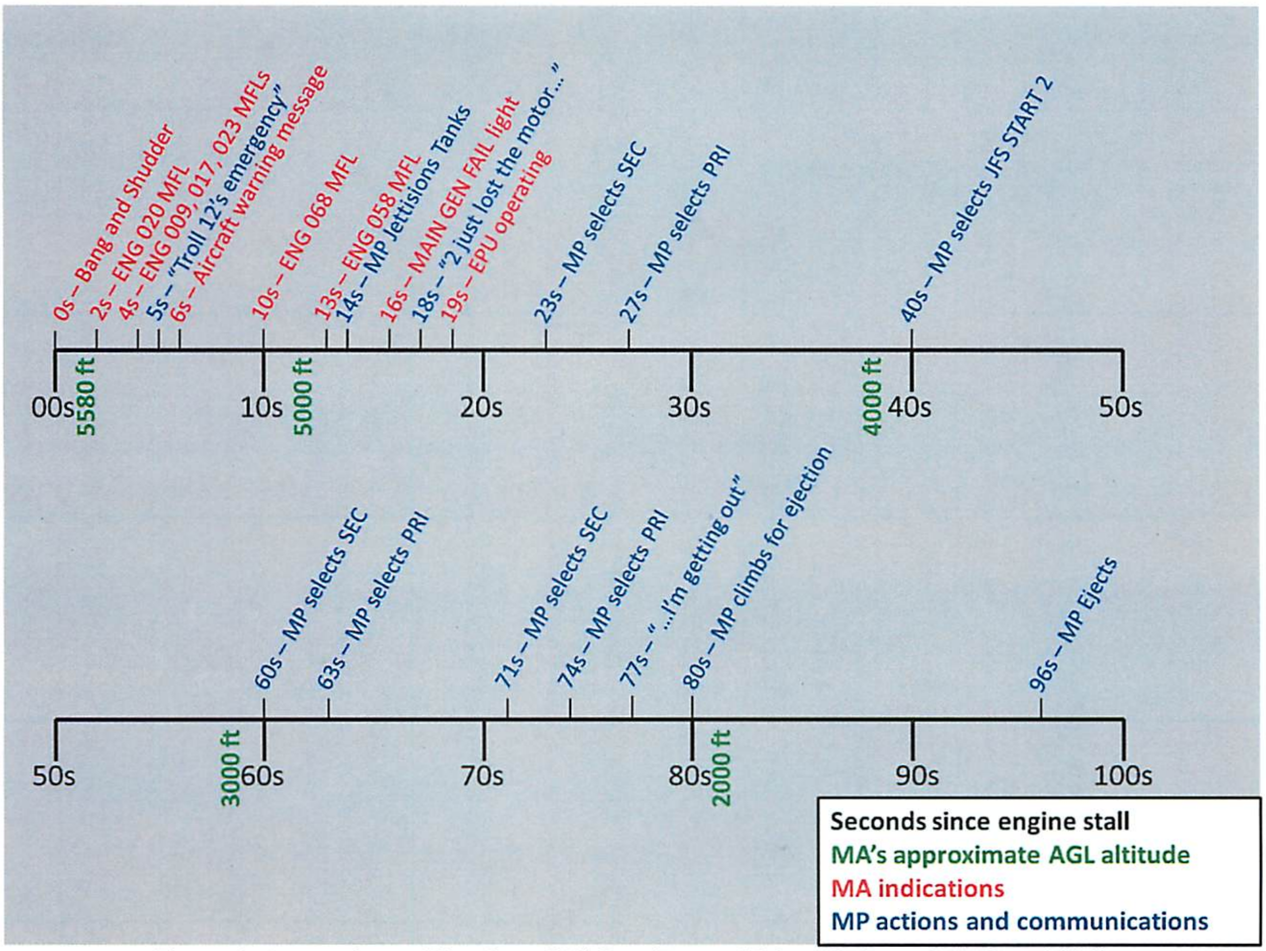

Figure 1. Approximate Timeline of Mishap Events (Tabs J-8 through J-11 and N-2)

e. **Impact**

The MA impacted the ground at approximately 14:30L, 50-55 nm west of Hill AFB, UT in the Great Salt Lake Desert. The debris field extended approximately 400 feet in a 180 degree arc west of the crater. The MA was destroyed on impact but large parts of the airframe were recognizable. (Tabs J-2 and S-4 through S-6) Figure 2 shows the MA's approximate flight path.

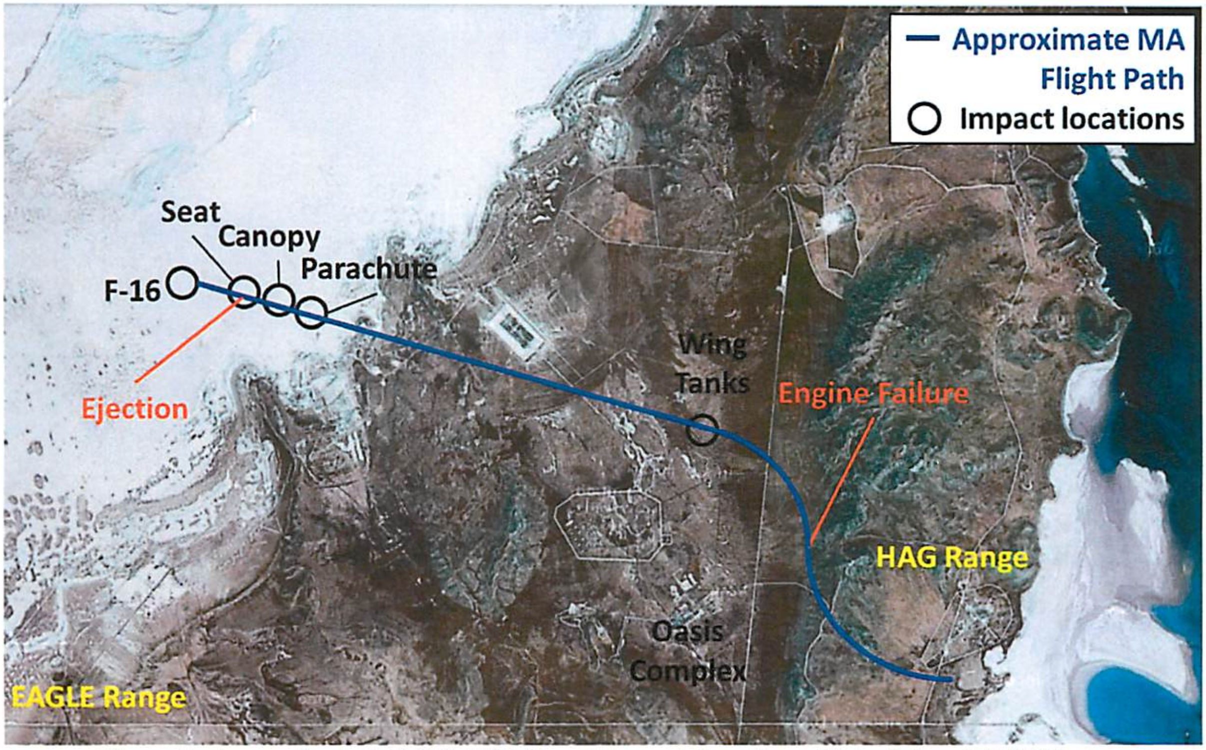

Figure 2. Approximate MA Flight Path and Impact Locations (Tabs S-2 and V-3.23)

f. **Egress and Aircrew Flight Equipment (AFE)**

The MP began a climb at approximately 6,100 ft MSL / 1,900 ft AGL, 240 KIAS, and 280 degrees MH in preparation for ejection. (Tab Z-4) The MP performed a smooth pull up to 26 degrees nose high and initiated ejection at 7,040 ft MSL / 2,840 ft AGL, 120 KIAS. (Tab Z-3) The MP ejected within recommended parameters for a controlled bailout. (Tabs V-3.14, V-4.10) The Advanced Concept Ejection Seat (ACES) II used Mode 1, consistent with the MA parameters at ejection and all escape system ballistic components functioned as designed. (Tab H-7) The MP's parachute functioned properly and he landed on a dry, flat area. The MP experienced no injuries. (Tabs V-3.16 through V-3.20)

All required AFE inspections were current and the MP was wearing the appropriate life support equipment for the mission. The AFE equipment was inspected post mishap and all components were in working condition. (Tabs H-9 through H-12, and V-3.15)

g. **Search and Rescue**

After the MP ejected, the MFL contacted Clover Control, the airspace control agency for the UTTR. The MFL reported Troll 12's ejection and passed the MP's approximate location. (Tabs

V-1.4, V-1.7 and V-4.11) Clover reported a downed aircraft and pilot to the Oasis Fire Department and the Hill AFB Supervisor of Flying (SOF). (Tab V-1.5 and Figure 2)

A paramedic with the UTTR Medical Aid Station was on duty in vicinity of the HAG range during the mishap and heard the MA on the range. After one of the MA's passes, the engine noise changed, sounding like the engine had failed. A few minutes later, the paramedic received a phone call from the police office reporting the downed MA. The paramedic responded with the fire department and used an all-terrain vehicle (ATV) to access the pilot's location. The paramedic arrived around 09:15L and noted that the MP was standing, conscious and alert with no injuries. (Tab R-3)

After the MP ejected, the MFL contacted the SOF at Hill AFB to report Troll 12's ejection and good parachute. A phone call from Clover confirmed the ejection. The SOF relayed this information to command post (CP) IAW the checklist. (Tabs V-1.5, DD-3 and DD-4)

The CP contacted Life Flight, a civilian rescue helicopter, at 08:51L and the helicopter departed at 08:56L to search for the MP. At approximately 09:25L, the helicopter transported the MP to McKay Dee Hospital, arriving at 10:03L. (Tab EE-3)

h. Recovery of Remains

Not applicable.

5. MAINTENANCE

a. Forms Documentation

A detailed 120-day review of records and forms was conducted. The 421st Aircraft Maintenance Unit maintained the aircraft forms for the MA. The aircraft forms are comprised of Air Force Technical Order (AFTO) 781-series forms, whose purpose is to document all discrepancies and maintenance actions performed on the MA. The Integrated Maintenance Data System (IMDS) is an automated database of aircraft discrepancies, maintenance repair actions, and flying history. Historical records and IMDS maintenance documentation were properly documented and complete. Prior to the MS, the MA accumulated 6,254.4 flight hours. There is no evidence that compliance with any reviewed historical maintenance records at Hill AFB was a factor in this mishap. (Tabs D-2 through D-36, U–18)

Time Compliance Technical Orders (TCTO) are inspections or maintenance procedures requiring completion on specific dates, flight hours, or engine operating hours. The AFTO 781-series forms and IMDS track compliance times and dates. No TCTOs restricted the MA from flying. Historical records showed all TCTOs were accomplished IAW applicable guidance. (Tabs D-33 and D-34, D-36, U-18)

The mishap engine (ME), an F110-GE-100-B, serial number GE0E09428, was overhauled in 2004 and installed in the MA on 21 December 2010. Between 2004 and 2010, the ME was installed in multiple aircraft with no defects noted. Historical records did not reveal any recurring maintenance problems. (Tabs D-2 and U–18)

b. General Scheduled Inspections and Procedures

The hourly post-flight inspection (HPO) is an in-depth flying-hour based inspection to ensure airworthiness of the aircraft, and is considered major maintenance. The F-16C is on a 400-hour HPO schedule. The MA underwent a 400-hour HPO in September 2010. No discrepancies were noted. (Tabs D-2 and V-2.7)

A Basic Post-flight/Pre-flight (BPO/PR) is a flight preparedness inspection performed by maintenance personnel prior to flight and is a valid inspection for 72 hours. The purpose of this inspection is to visually inspect and operationally check various areas and systems of the aircraft in preparation for a flying period. The last BPO/PR inspection was completed on 3 May 2012 at 23:30L. The BPO/PR was current and no defects were noted. (Tabs D-19 through D-21, U-18)

On 06 March 2012, a scheduled Weight and Balance (W&B) inspection was accomplished IAW technical data. The MA was scheduled as a non-flyer for the duration of the W&B and all follow-on and operational checks and maintenance documentation were accomplished without defect. (Tab U-18)

The MA underwent an extensive Egress Time Change Inspection (TCI) in April 2012. The canopy and ejection seat, a majority of cockpit console panels and forward avionics bay system LRUs were removed to facilitate this TCI. All follow-on maintenance, operational checks, and documentation were complied with. (Tab U–18)

c. Maintenance Personnel and Supervision

All pre-mission maintenance was conducted during an ORE and all personnel involved in the preflight, servicing, inspecting, and launch of the MA were qualified and proficient in their duties. Maintenance training records (AF Forms 623 and 797) revealed no training deficiencies. (Tab U-18)

d. Fuel, Hydraulic and Oil Inspection Analyses

Fuel, oil lubricants, and hydraulic samples from the fuel truck, service carts, and MA were sent for analysis. All samples met material test requirements. Additionally, inspection records on the servicing carts used on the MA were current. (Tab D-71)

e. The F110-GE-100 Turbofan Engine

(1) Description and Operation:

The F110-GE-100 series engine is an augmented, mixed-flow turbofan engine. Its design includes five major assemblies, also called shop replaceable units (SRUs). From front to back, these five major assemblies are the fan, high pressure compressor, combustor case, high pressure turbine (HPT), and the low pressure turbine (LPT) assemblies. Each SRU may have additional field-level line replaceable units (LRU) installed and undergoes intensive inspections. (Tabs U-19 through U-20 and V-2.11 through V-2.12)

The fan assembly's primary purpose is to pressurize air and direct flow into the engine. This assembly is comprised of variable inlet guide vanes (IGV), the fan stator assembly, and the fan assembly. The fan rotor has three stages of blades. The first fan stage has 32 blades. The fan assembly is driven by the LPT via a shaft. (Tabs U-19 through U-20)

The high pressure compressor includes a nine-stage compressor, a combustion chamber, and the HPT. The compressor's primary purpose is to compress air in order to create a dense, oxygen-rich environment for ignition by spark igniters in the combustion chamber, thus creating thrust. (Tabs U-19 through U-20)

As this fuel/air mixture exits the combustion chamber, expanding gases are directed into the HPT (powering the compressor) and the LPT (driving the fan). The HPT and LPT are mechanically independent of each other. The air is then directed to an augmenter section, also known as the afterburner, and then the exhaust nozzle. (Tabs V-2.3 through V-2.7, U-19 through U-20, Z-7 and Z-8) Figure 3 depicts the basic F110-GE-100 engine layout.

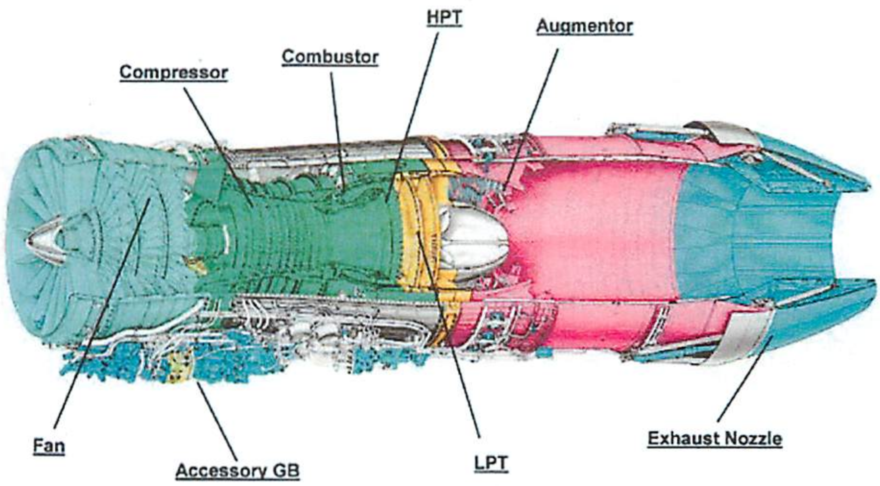

Figure 3. F110-GE-100 Engine (Tab J-20)

The jet fuel starter (JFS) is a small gas turbine engine that connects to an accessory gearbox which drives the engine to an RPM suitable for start. As RPM increases in the core (N2 speed) and airflow is directed through the LPT, the fan assembly starts to rotate (N1 speed). Engine temperature is displayed as Fan Turbine Inlet Temperature (FTIT). As the engine is rotating, fuel is ignited in the combustion section, which increases both N1 and N2 speed. Once the engine reaches operating speed, the JFS shuts down. (Tabs V-3.14, V-2.3 through V-2.4)

The emergency power unit (EPU) is a self-contained system providing emergency hydraulic pressure and electrical power. The EPU automatically activates when both generators fail or when both hydraulic system pressures fall below 1000 pounds per square inch (psi). (Tabs J-12 and V-4.9 through V-4.12)

(2) Scheduled Hourly Engine Inspections

All scheduled engine inspections were current. The 100 and 200-hour borescope inspections are based on engine operating time. These inspections consist of using a fiberoptic camera to search for basic surface anomalies on visible sections of the SRUs. The 200-hour inspection is more comprehensive. Qualified maintenance technicians performed the inspection IAW procedures. The inspections were current and without defect. (Tabs U-18 and V-2.9)

A 400-hour engine inspection and 400-hour aircraft inspection were accomplished concurrently on 9 September 2010. No mishap-related defects were noted in either inspection. (Tabs D-2, D-27, U-18)

(3) The 4,000 Total Accumulated Cycle Inspection

The 4,000 Total Accumulated Cycle (4K TAC) is the most involved intermediate-level inspection. A TAC is a calculation of engine RPM and throttle usage in terms of cycles between varying power settings. A cycle considers the temperature range and stress factors associated with continuous heat variances on the engine. 4K TAC inspections are preventative measures to ensure component integrity. (Tabs U-8 through U-10, V-2.8, and V-2.9)

During the inspection, the engine is removed and sent to the engine backshop for disassembly. The fan assembly is removed and sent to engine depot at Tinker AFB, Oklahoma for inspection and/or refurbishment. (Tabs V-2.9 through V-2.13)

The ME underwent a 4K TAC inspection in April 2004. The fan assembly was disassembled and individual parts were sent to various shops at Tinker AFB for inspection, repair, or replacement. The stage 1, 2, and 3 fan blades were removed and sent to the blade-building facility. (Tabs U-3 through U-6, U–11 through U-17, V-2.12, V-7.2)

The fan blades underwent cleaning, visual inspection, repair, and replacement. Due to their unique function in an ever-changing environment, these blades are precisely measured, marked, balanced, and installed on the fan assembly. (Tabs U–11 through U-17, V-7.2, V-7.5, V-9.2 through V-9.4) Figure 4 depicts a detailed view of the fan blade.

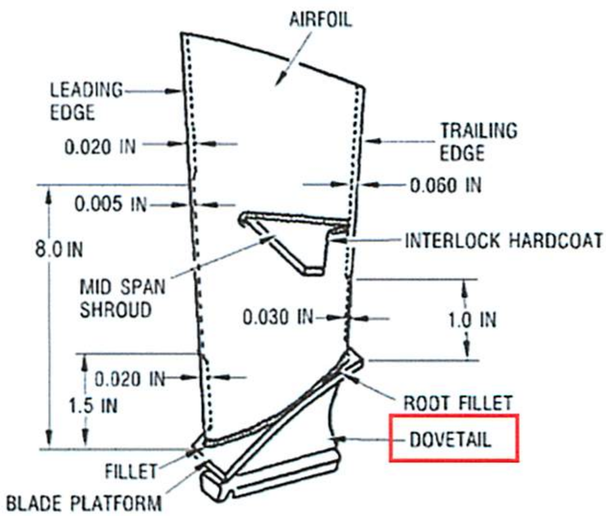

Figure 4. Stage 1 Fan Blade (Tab V-2.34)

On 20 April 2004, a full set of 32 new fan blades (straight from the manufacturer) were installed on the ME fan assembly. (Tabs U–11 through U-17) Each blade undergoes individual inspection prior to installation. (Tabs V-9.6 through V-9.8 and V-9.11) Figure 5 shows the inspection criteria for the dovetail portion of the blade. (Tabs U-19 through U-20)

Inspect	Max Serviceable Limits	Max Repairable Limits	Corrective Action
8. Dovetail for:			
a. Fretting on Pressure Face	Not Serviceable	Not Repairable	Replace stage 1 fan blade
b. Missing or chipped coating on pressure faces	Not Serviceable	Any Amount	Replace coating (TO 2J-F110-3-6, WP 018 00)
c. Nicks, dents scratches, or scores other than on pressure face or adjacent fillet radii	Any number, any length, 0.005 inch deep. None allowed in fillet radii or across corners. Any amount, 0.005 inch deep allowed on edge of bottom dovetail surface	Not Repairable	Replace stage 1 fan blade
d. Used coating on pressure faces	Not Serviceable	Any Amount	Replace coating (TO 2J-F110-3-6, WP 018 00)
e. Cracks	Not Serviceable	Not Repairable	Replace blade
f. Nicks, dents, scratches, or scores in fillet radii or across corners	Not Serviceable	Any number, 0.010 in deep	Blend (TO 2J-F110-3-6, WP 003 00)
9. Dovetail end faces for:			
a. Wear	Any amount, 0.005 inch deep	Not Repairable	Replace stage 1 fan blade

Figure 5. Stage 1 Fan Blade Inspection, Dovetail Section (Tabs U-19 through U-20)

All 32 stage 1 fan blades were individually weighed, inspected and installed on the ME fan assembly for an initial balance check. Once properly balanced, the assembly was reinstalled onto the ME. (Tabs U–11 through U-17, V-9.10 through V-9.12) No maintenance documents indicate removal of any first stage fan blades since installation in April 2004. (Tabs U-3 through U-7 and U-18) The ME operated effectively for approximately 8 years, accumulating 972.4 engine operating hours and 1,947 TACs before the mishap sortie. (Tabs J-18 and J-19)

f. Unscheduled Maintenance

Unscheduled maintenance is any maintenance action that is not the result of a scheduled inspection. This maintenance is normally the result of a pilot-reported discrepancy or a condition discovered by ground personnel. Unscheduled maintenance was performed on the MA on the evening of 3 May 2012 for a fuel system #5 boost pump light illumination failure. Fuel shop personnel troubleshot the discrepancy, removed and replaced a pressure switch under panel 4402, and checked the system with no further defects noted. All follow-on actions and operational checks were completed and properly documented. (Tabs D-22 through D-23, R-38 and U-18)

6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS.

a. Structures and Systems

At impact, the MA broke apart significantly. The vertical tail was visible in the impact crater, but the wings, right horizontal tail box and exhaust nozzle had separated. (Tabs J-2 through J-3) Lockheed Martin Aeronautics conducted a post mishap analysis of the crash survivable memory unit (CSMU), the Data Flight Control System Memory, and the Signal Acquisition Unit. All aircraft systems operated properly during the MS. (Tab J-16) The JFS and EPU were running at impact. (J-17) The MA digital video recorder was damaged but the HUD video was forensically extracted. (Tab Z-5)

b. Evaluation and Analysis

(1) Crash Survivable Flight Data Recorder

Data recovered from the crash survivable flight data recorder (CSFDR) showed that at approximately 08:27L, the engine experienced a rapid first stage fan slowdown, reducing to virtually zero within 0.6 seconds. (Tabs J-8 through J-11, J-31) At the same time, the engine core temperature began to increase due to lack of airflow to cool the engine. Within approximately fifteen seconds, a compressor stall maintenance fault recorded, engine core speed reduced to below idle and the emergency power unit (EPU) started. (Tabs J-8 through J-11 and V-8.7 through V-8.13)

The EPU automatically activates when both generators fail, or when both hydraulic system pressures fall below 1000 psi. (Tab J-12) The EPU does not provide thrust, and only powers electrical systems and hydraulics. (Tab V-4.10 and V-8.13) The MA maintained sufficient hydraulic flow up to ejection, and the EPU activated based on generator failure. (Tab J-7) The MP attempted three unsuccessful airstarts, and the engine continued to windmill. The engine core continued to rotate due to air speed, but provided no thrust. (Tabs J-8 through J-11, V-3.14, and V-8.15) At approximately 08:30L, the MP "zoomed" the aircraft by slowing down, gaining altitude, and successfully ejected. (Tabs J-2 and V-3.14) All systems except the engine operated as designed. (Tabs J-7, J-11, and J-16)

(2) Engine Analysis

Engineering analysis of the CSFDR indicates the engine experienced a compressor stall followed by a steady rollback of the engine core RPM and an increase in temperature. (Tab J-18) Evaluation of the engine showed heavy mechanical damage to the fan, a titanium fire to the compressor, and heavy burning of the turbine, including the HPT and LPT. Engine damage is consistent with failure of blade 17 in the first stage fan. (Tabs J-18 through J-32)

The fan assembly exhibited extensive damage due to impact and ingested blade parts. On the first stage fan, blade 17's dovetail was still attached to the rotor, but the airfoil was broken off. A remnant of 17's airfoil was found inside the fan section and exhibited severe mechanical damage. Six inches of blade 17 was never recovered. (Tab J-21) Figure 6 shows the three fan stages with rotors and blades. Figure 7 depicts the first stage rotor and a single blade.

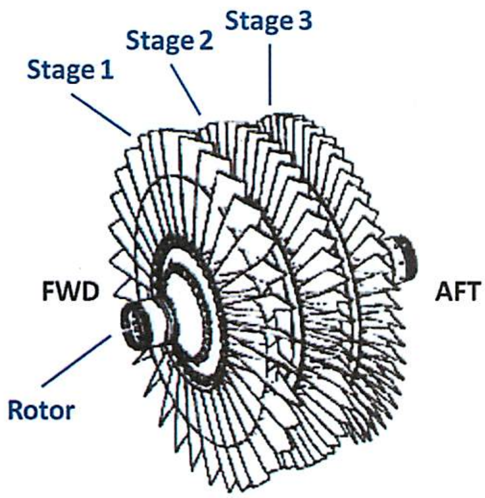

Figure 6. Fan Stages 1, 2, and 3 (Tab V-2.39)

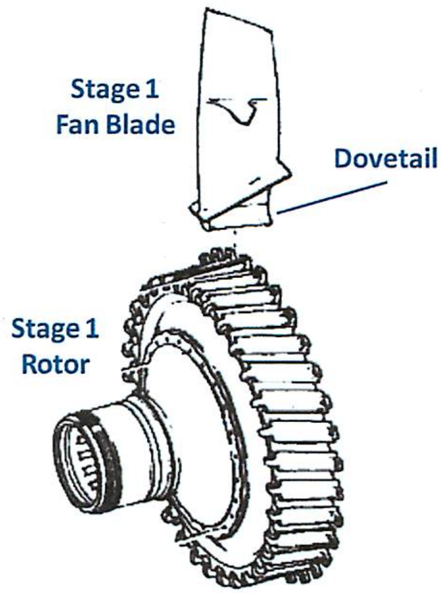

Figure 7. Stage 1 Fan Blade and Rotor (Tab V-2.34)

Blade 16, the next blade in the direction of fan rotation to blade 17, had damage to the center of the platform edge adjacent to blade 17. Blade 15 had liberated approximately 2 inches from the tip. (Tab J-21)

Evaluation of the dovetail slots on the first stage fan rotor showed imprints at every location except blade 17. (Figure 8) This indicates that the first stage fan blades and dovetails experienced imbalance and improper stress, except blade 17. This further shows that blade 17 was not in place at the time of imbalance. (Tabs J-21 through J-22)

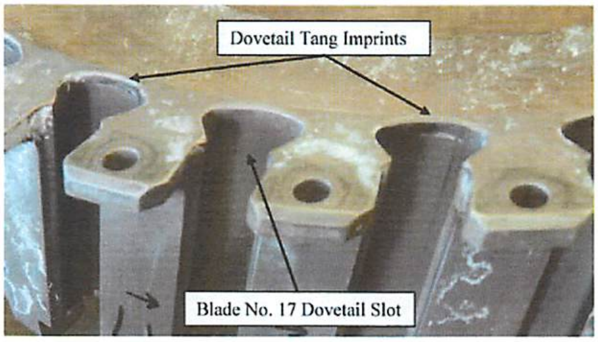

Figure 8. Fan Blade Rotor Dovetail Slots (Tab J-22)

The stage 2 and 3 blades all exhibited mechanical damage in the form of missing material, nicks and dents. Five consecutive stage 2 blades were missing approximately 1 inch of the blade tip. These blades were located in line with stage 1 blade number 17 and in the direction of rotation. (Tabs J-21 through J-23)

Analysis of the compressor found missing material, nicks, and dents in the stage 1 and 2 fan blades. The compressor also exhibited signs of burning. This is indicative of ingestion of foreign objects into the compressor, and a lack of airflow to cool the area. (Tabs J-26 through J-28, V-2.24)

(3) Metallurgical Analysis

Analysis of physical evidence indicates blade 17 in the first stage fan assembly separated from its base during flight. (Figures 9 and 10) The separation was due to fatigue cracking that propagated from the edge of an anomaly until final tensile overload occurred. (Tab J-34)

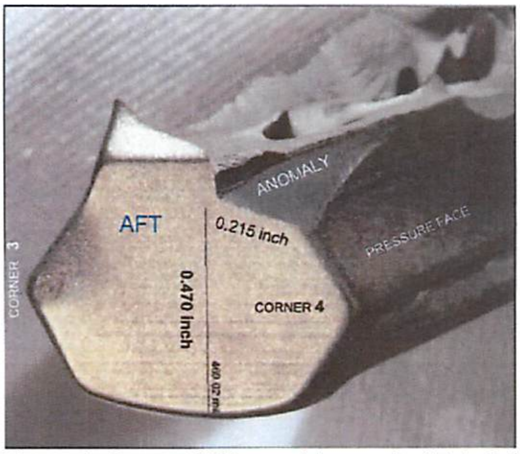

Figure 9. Dovetail View w/ Anomaly (Tab J-41)

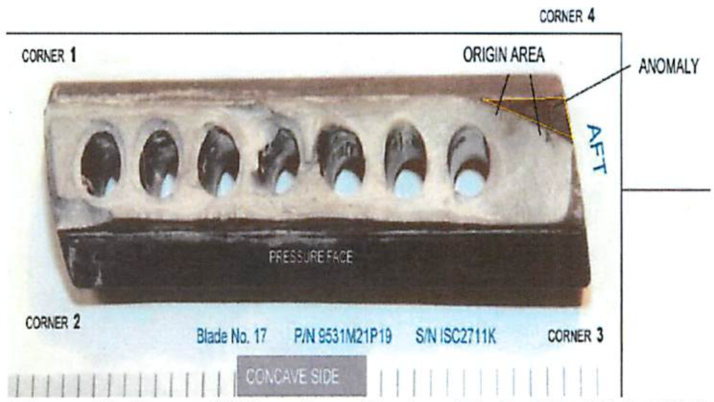

Figure 10. Dovetail View from Broken Blade Side (Tab J-36)

Metallographic evaluation revealed that the surface anomaly was formed during the manufacturing process at temperatures only encountered at forging, and not during normal engine operation. Fan blade 17 separated about 0.5 inches from the blade root. The crack causing blade separation originated at corner 4 (aft end on the convex side), along the edge of the surface anomaly. The fracture surface was consistent with crack initiation and propagation by high alternating stress and low cycle fatigue from normal engine operation. Regular engine use caused cracking to form at the edge of the anomaly, eventually resulting in blade separation. (Tabs J-34 through J-36)

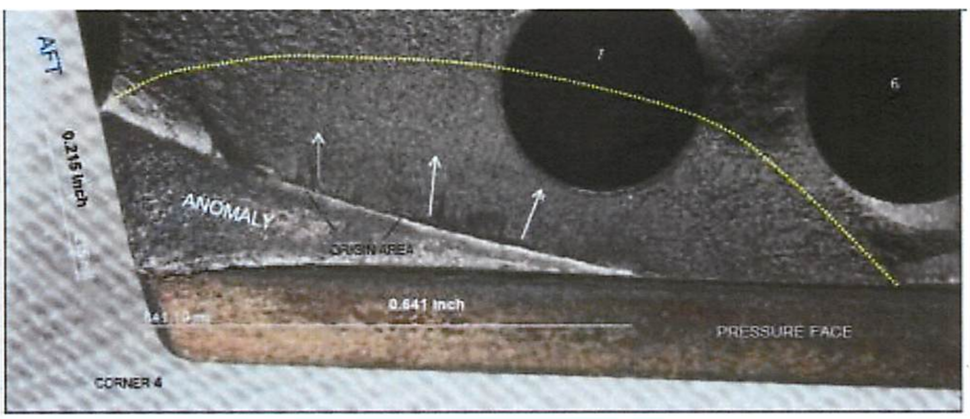

Figure 11. Magnified View of the Anomaly (Tab J-39)

Figure 11 depicts a close up of the triangular surface anomaly at corner 4 on the pressure face. The anomaly measured 0.215 inches along the aft face, 0.641 inches along the shank surface, and 0.739 inches along the fatigue origin area. The white arrows indicate the fatigue cracks emanating from the anomaly edge. The dotted yellow line depicts the boundary of the fatigue region, prior to tensile overload. Since the anomaly resulted from the manufacturing process, the changed surface area would be present at the time of the installation inspection. (Tab J-39)

Based on the blade inspection checklist in Figure 9, the anomaly falls within parameters mandating replacement, specifically under section 8(c). The inspector could have noticed the anomaly based on its size and location, as it was significantly larger than a nick or dent. The blade was not replaced during the visual inspection at Tinker AFB during fan assembly buildup. (Tabs U-19 through U-20 and V-9.11 through V-9.12) After the initial blade installation at the 4K TAC in April 2004, no scheduled inspection or maintenance would have permitted discovery of the anomaly. (Tabs V-2.25 through V-2.27)

7. WEATHER

a. Forecast Weather

At brief time, the range weather was forecast to have scattered cloud layers from 10,000 to 15,000 feet AGL. Skies were clear with winds out of the west at 10 knots gusting to 15 knots. (Tab F-4)

b. Observed Weather

The weather during the MS around the mishap area was scattered cloud layers starting at 10,000 ft MSL. The cloud layer thinned out to the west. There was no precipitation during the MS. (Tabs V-4.8 and V-4.15)

c. Space Environment

Not applicable.

d. Operations

Due to the cloud layer at 10,000 MSL, the MFL and MP flew below the clouds. This allowed the F-16 sensors to view the ground for the CAS mission. The lower altitude decreased the amount of time the MP had to restart the engine and limited the distance that the MA could travel prior to ground impact. (Tabs V-4.8 and V-4.14)

8. CREW QUALIFICATIONS

The MP was a current qualified instructor pilot (IP) and mission commander with 898.6 total flying hours in the F-16C, and 65.1 IP hours. (Tabs G-2 and G-3)

The MP met all currency and training requirements prior to the mishap sortie, and was qualified for the mission. (Tabs G-2 through G-30) The MP is an exceptional officer and IP. The speed at which the MP upgraded to IP shows that his leadership and aviation abilities were above average. (Tab V-5.9)

At the time of the mishap, the MP's recent flight time was as follows (Tab G-14):

	Hours	Sorties
Last 30 Days	2.5	2

Last 60 Days	15.9	11
Last 90 Days	35.3	23

9. MEDICAL

a. Qualifications - Mishap Pilot

A review of the MP's medical record showed he was medically qualified for flight and worldwide duty. His most recent annual flight physical and Periodic Health Assessment were performed on 31 Oct 2011. He has an indefinite waiver for failed depth perception granted on 1 December 2008. His original waiver was granted at the time of his Initial Flying Class physical on 17 Jan 2003 and he has not failed a depth perception test since his initial examination. (Tab X-4)

b. Health

Medical records and individual history revealed the MP was in good health. There was no evidence that any preexisting medical condition contributed to this mishap. (Tab X-3 and X-4)

c. Pathology

There were no fatalities or injuries of any personnel resulting from this mishap. (Tab V-3.20) Toxicology testing was performed on MP, MFL, and 25 maintenance personnel. Drug or medication use was not a factor in the mishap and had no effect on the MA's maintenance. (Tab X-3)

d. Lifestyle

No lifestyle factors were relevant to the mishap. (Tab X-3)

e. Crew Rest and Crew Duty Time

Crew rest requirements were 12 hours for the MP and MFL prior to the mission on the day of the mishap. Crew rest requirements were met for the aircrew. (Tabs V-3.6 through V-3.8, V-4.6, and V-6.4)

10. OPERATIONS AND SUPERVISION

a. Operations

The 421 FS was participating in a wing ORE at the time of the mishap. An ORE is organized into phase 1 and phase 2. In phase 1, the squadron prepares for simulated combat operations by fixing aircraft and loading munitions. In phase 2, the squadron flies with simulated munitions and executes missions similar to wartime requirements. The flying portion of the ORE started on 3 May 2012, the day prior to the mishap. (Tabs V-4.4, V-4.5, and V-5.3)

The 421 FS deployed to the Republic of Korea (ROK) for about 6 months where they participated in four OREs. The squadron returned to Hill AFB in early April 2012. Due to the high operations tempo in the ROK, the squadron was exceptionally combat ready upon their return. (Tabs V-5.2 and V-5.5) The squadron had three weeks of leave and time to set up normal operations after their return and prior to the ORE at Hill AFB. (Tabs V-3.4, V-3.5, and V-5.5)

b. Supervision

As part of the 388 FW, the 421 FS, 4 FS, and 466 FS operated as a combined squadron to conduct flying operations during the ORE. The 466 FS is an Air Force Reserve unit at Hill AFB. Although scheduling and planning was a combined effort, the 466 FS acted as the squadron level supervision for all three fighter squadrons in the ORE. The MP worked directly for the 421 FS commander as a flight commander and was supervised by the 466 FS leadership at the time of the mishap. (Tabs V-5.9 and V-6.8) Supervision of the squadron and MP was appropriate.

11. HUMAN FACTORS

There is no evidence that human factors contributed to this mishap.

12. GOVERNING DIRECTIVES AND PUBLICATIONS

a. Directives and Publications Relevant to the Mishap

(1) T.O. 1F-16CM-1, *F-16C/D Flight Manual*, 1 July 2011
(2) T.O. 1F-16CM-1CL-1, *F-16 Flight Crew Checklist*, 15 April 2007, IC 1 July 2011
(3) T.O. 2J-F110-3-5, *Maintenance Instructions Depot Level F110-GE-100 Turbofan Engine*, 1 September 2001
(4) T.O. 2J-F110-6-1 WP003-00, *Work Package*, 31 October 2001, IC 1 December 2011
(5) AFI 11-2F-16V1, *F-16 Aircrew Training*, 11 August 2011
(6) AFI 11-2F-16V3, *F-16 Operations Procedures*, 18 February 2010
(7) AFI 48-123, *Medical Examinations and Standards*, 20 September 2011
(8) Air Force Waiver Guide, 27 April 2012

NOTICE: The AFIs listed above are available digitally on the AF Departmental Publishing Office internet site at: **http://www.e-publishing.af.mil**.

13. ADDITIONAL AREAS OF CONCERN

None

Thomas R. Olsen, Jr.

6 AUGUST 2012

THOMAS R. OLSEN, JR., LT COL, USAF
President, Accident Investigation Board

STATEMENT OF OPINION

F-16C, T/N 88-0433
Utah Test and Training Range (Near Hill AFB, UT)
4 May 2012

Under 10 U.S.C. 2254(d), any opinion of the accident investigators 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

On 4 May 2012, at approximately 08:30 hours local time (L), an F-16C, tail number 88-0433, assigned to the 421st Fighter Squadron, 388th Fighter Wing (388 FW), Hill Air Force Base (AFB), Utah, crashed in the northern portion of the Utah Test and Training Range (UTTR), approximately 50 nautical miles west of Hill AFB. No military or civilian personnel were injured in the mishap. The mishap aircraft (MA) was destroyed on impact, with no damage to private property. Mishap damage costs were $23,869,281.

The mishap pilot (MP) was conducting close air support training as the second aircraft in a two-ship formation, when he reported an engine failure. Immediately following indications of a compressor stall and engine failure, the MP maneuvered west to avoid mountainous terrain and the Great Salt Lake. He correctly applied all critical action procedures and coordinated with his mission flight lead to initiate search and rescue operations.

Due to low altitude at engine failure, recovery to any runway was impossible, regardless of pilot action. After several unsuccessful attempts to restart the engine, the MP placed the MA in a stable, climbing attitude. The MP safely ejected approximately one and a half minutes after the initial compressor stall indication. UTTR emergency response crews and a local Life Flight helicopter recovered the MP.

I find, by clear and convincing evidence, the cause of the mishap was failure of the number 17 blade in the first stage fan section of the engine. The fan blade liberated from its supporting structure, causing catastrophic damage to the rest of the fan, compressor, and high and low pressure turbines. Because of this extensive damage, the engine could not produce thrust or be restarted.

Additionally, I find, by a preponderance of the evidence, a blade anomaly coupled with eight years of normal operating fatigue substantially contributed to the mishap. The anomaly at the base of blade 17 was formed during a manufacturing process. Blade 17 separated due to fatigue cracking propagating from the edge of the anomaly.

I also find, by a preponderance of the evidence, the failure to detect the anomaly during the installation inspection process in 2004 substantially contributed to the mishap.

I developed my opinion by analyzing factual data from historical records, Air Force directives and guidance, Air Force Technical Orders, engineering analysis, witness testimony, flight data, flight simulations, animated simulations, and information provided by technical experts.

2. DISCUSSION OF OPINION

a. Cause

Evidence from the engine tear down analysis indicates the MA experienced a catastrophic engine failure due to liberation of the number 17 fan blade from the engine's first stage fan. The fan blade, once liberated from its supporting structure, damaged all subsequent sections of the engine. Because of this extensive damage, the engine could not produce thrust or be restarted. All maintenance inspections and procedures since blade installation in 2004 were completed appropriately and could not prevent the mishap.

b. Contributing Factors

(1) Contributing Factor 1

Fan blade 17 separated due to an anomaly at the base of the blade. Metallurgical analysis indicates the anomaly was created during a manufacturing process. Normal engine operation or maintenance actions could not cause the anomaly. Eight years of operating fatigue caused cracking that propagated from the edge of the anomaly until final tensile overload occurred.

(2) Contributing Factor 2

The surface anomaly on blade 17 was caused during the manufacturing process, as only forging temperatures could cause the discrepancy. Since the anomaly was caused during manufacturing, it would have been present during the installation inspection. Photos of the blade clearly show the anomaly on the surface of the dovetail. Prior to installation, blade 17 underwent a visual inspection of the dovetail surfaces and corners. The inspection process required a visual examination looking for nicks, dents, scratches and/or wear on the blade base. The visual inspection checklist mandates discarding blades with such an anomaly based on its size and location. The anomaly fell within category 8(c) on the inspection checklist, as it was at a very minimum a dent or nick on the surface of the dovetail. The blade was nevertheless installed on the fan rotor after inspection. The blade was never removed after 2004 and no post-installation maintenance procedure performed would have revealed blade 17's anomaly.

3. CONCLUSION

I find, by clear and convincing evidence, the cause of the mishap was failure of the number 17 fan blade in the first stage fan section of the engine. This caused extensive damage leading to the unrecoverable engine failure. Further, by a preponderance of the evidence, I find a blade anomaly coupled with eight years of normal operating fatigue substantially contributed to the mishap. I also find, by a preponderance of the evidence, the failure to detect the anomaly during the installation inspection process in 2004 substantially contributed to the mishap. The MP demonstrated exceptional poise and situational awareness during the mishap sequence.

6 AUGUST 2012

THOMAS R. OLSEN, JR., LT COL, USAF
President, Accident Investigation Board

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