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## EXECUTIVE SUMMARY

## AIRCRAFT ACCIDENT INVESTIGATION
## F-16C, S/N 86-0284

## CANNON AIR FORCE BASE, NEW MEXICO
## 12 JULY 1999

On 12 July 1999, at 0831 MDT (1431 Zulu), a F-16C, S/N 86-0284, crashed 85 nautical miles SSE of Cannon AFB. The F-16C, assigned to the 523d Fighter Squadron, 27th Fighter Wing, Cannon AFB, was part of a four-ship formation on a tactical intercept Mission Qualification Training sortie in the BRONCO Military Operating Area. The pilot, Captain Jason L. Marshall, of the 523d Fighter Squadron ejected safely with only minor injury. Property damage was minimal and consisted of damage to barbed wire fences, gouging of pasture land, and minor damage to a gravel county road. There were no civilian injuries or casualties.

Five minutes before impact, the pilot reported an engine failure and flameout while at an altitude of 16,260' MSL. ARGOS 04, the wingman, noticed a large orange-red fireball and smoke emerge from the rear of the mishap aircraft. The mishap pilot accomplished the critical action procedures for an engine failure and attempted two airstarts while turning in the general direction of a suitable emergency airfield. The pilot performed required emergency procedures; however, airstarts were unsuccessful and he judged his flight conditions (airspeed, altitude, and remaining distance to an emergency airfield) would not allow a successful glide and recovery. The pilot turned the aircraft towards an uninhabited area and at 5,500' MSL, accomplished pre-ejection procedures, zoomed the aircraft to gain altitude, and initiated a successful ejection with only minor injury. The aircraft impacted the ground approximately 20 seconds after pilot ejection.

The primary cause of the mishap supported by clear and convincing evidence, was a non-recoverable in-flight engine shutdown caused by a catastrophic failure in the High Pressure Turbine (HPT) assembly. The HPT failed when two HPT blades separated due to fatigue. Beyond gliding distance to the nearest emergency airfield, the pilot was forced to eject. Convincing evidence suggests the separation of portions of the HPT dovetail disk posts in the upper pressure face area caused the fatigue failure of the HPT blades in the minimum neck area and eventual blade separation. A casual factor in separation of pieces from the dovetail disk posts were pressure face surface dimensions that exceeded the maximum drawing stack specifications potentially due to disk deformation after high Total Accumulated Cycles.

*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 may not be considered as evidence in any civil or criminal proceeding arising from an aircraft accident, nor may such information be considered an admission of liability by the United States or by any person referred to in those conclusions or statements.*



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## 1. AUTHORITY, PURPOSE, AND CIRCUMSTANCES

### a. Authority.

On 18 August 1999, General Ralph E. Eberhardt, Commander Air Combat Command (ACC) appointed Colonel Frederick R. Strain to conduct an aircraft accident investigation of the 12 July 1999 crash of an F-16C aircraft, serial number 86-0284, in the Bronco 3 MOA, 80 NM SSE of Cannon Air Force Base, New Mexico. The investigation was conducted at Cannon Air Force Base, New Mexico, from 23 August 1999 through 8 September 1999. Technical advisors were Major Robert Weiland (Pilot), Major Daryl L. Bell (Legal), Major Richard Sumrall (Medical), Chief Master Sergeant Ralph Huntington (Maintenance), and Senior Master Sergeant Brian P. McDonald (Propulsion), (Tab Y-2).

### b. Purpose.

This aircraft accident investigation was convened under Air Force Instruction (AFI) 51-503. The primary purpose is to gather and preserve evidence for claims, litigation, and disciplinary and administrative actions. In addition to setting forth factual information concerning the accident, the board president is also required to state his opinion as to the cause of the accident or the existence of factors, if any, that substantially contributed to the accident. This investigation is separate and apart from the safety investigation, which is conducted pursuant to AFI 91-204 for the purpose of mishap prevention. The report is available for public dissemination under the Freedom of Information Act (5 United States Code (U.S.C.) §552) and AFI 37-131.

### c. Circumstances.

The accident board was convened to investigate the Class A accident involving an F-16C aircraft, S/N 86-0284, assigned to the 523$^{rd}$ Fighter Squadron, 27$^{th}$ Fighter Wing, Cannon Air Force Base, New Mexico, which crashed on 12 July 1999.

## 2. ACCIDENT SUMMARY

Aircraft F-16C, SN 86-0284, experienced engine failure on 12 July 1999 80nm SSE of Cannon AFB, NM and impacted the ground approximately 15nm further SSE (Tab A-2, R-3). The Mishap Pilot (MP), Captain Jason L. Marshall, was number three (call sign ARGOS 03) of a four ship flight of F-16C aircraft scheduled for a tactical intercept Mission Qualification Training (MQT) sortie (Tab K-4). The MP ejected safely with only minor injury (Tab X-2). The Mishap Aircraft (MA) impacted the ground, but remained relatively intact with a comparatively small debris field (Tab S-2 through S-4). The aircraft was judged destroyed with a total loss value of $18,962,745.19 (Tab M-2). Damage to private property was minimal and limited to barbed wire fencing (Tabs Z-1, Z-2), a small portion of pastureland (Tab S-2), and minor damage to County Road 73 (Tab S-3) to include the spilling of approximately 600 gallons (3,700lbs) of JP-8 fuel (Tab 0-31 through O-35). The fence and road damage was repaired by the 27$^{th}$ Civil Engineering Squadron (Tab Z-3 through Z-6) and the fuel spill cleaned up through private contract (Tab DD-

62). The 27th Fighter Wing Public Affairs Office at Cannon AFB, NM provided the official USAF News Release and handled media inquiries about the mishap. Media interest was low with mostly local media covering the story (Tab EE).

## 3. BACKGROUND

The 27th Fighter Wing at Cannon AFB, New Mexico maintains an F-16 wing capable of day, night, and all weather combat operations worldwide. The wing's assigned F-16 pilots must maintain currency in air-to-air and air-to-ground combat operations. The 523d Fighter Squadron is a component of the 27th Fighter Wing. The 27th Fighter Wing and its subordinate units are all components of the Air Force's Air Combat Command (Tab EE-4).

## 4. SEQUENCE OF EVENTS

### a. Mission.

This was a tactical intercept Mission Qualification Training (MQT) sortie (Tab K-4). The planned mission profile included formation takeoff, a rejoin to a "two plus two" offset container, tactical intercepts, air refueling, additional tactical intercepts, and then return to base (Tabs A, K-3, V1, V2, V3, V4). The MP, Captain Jason L. Marshall, was number three (call sign ARGOS 03) of a four ship flight of F-16C aircraft and functioned as the deputy flight lead and together with ARGOS 04, the red air element simulating enemy aircraft (Tabs A, K-4,V-1 Pg. 1-3). The mission was authorized in flight orders signed on 12 July 1999 by Major W.M. Sipher (Tab K-4).

### b. Planning.

Initial mission planning for the sortie was conducted on 11 July 1999 and included a "line-up card," visual flight rules chart of the BRONCO Military Operating Area, and Data Transfer Cartridge (Tab V-3). The Accident Investigation Board did a thorough review of mission planning and briefing procedures and is confident required actions were conducted in accordance with USAF, ACC, and local procedures. The MP attended the mass briefing for daily flyers on the morning of 12 July 1999 where weather, NOTAMs, and squadron special interest items were addressed (Tabs V-1 Pg. 3, V-3 Pg. 1). The weather briefing indicated VMC conditions and no warnings or advisories in effect (Tab K-6). Capt Marshall signed the daily flight orders as pilot in command of ARGOS 03 (Tab K-4). The ARGOS flight leader, Capt Douglas Miller, conducted the four-ship flight mission briefing covering all mission items pertaining to four-ship procedures to include emergency contingencies and the location of divert/emergency airfields in accordance with all governing instructions and directives (Tab V-3 Pg. 1). All flight members stated they fully understood all mission elements and no pilot noted any unusual occurrences or issues during mission planning or briefings (Tabs V1, V2, V3, V4). Following the flight leader's briefing, ARGOS 01/02 and ARGOS 03/04 separated for the purpose of conducting individual "Red Air" and "Blue Air" element briefings. Capt Marshall conducted the element briefing for ARGOS 03/04 (Tab V-2 Pg. 1). Following the element briefings the MP stepped to the jet.

c. Preflight.

At the step briefing, the MP volunteered to swap aircraft with ARGOS 02 and take aircraft S/N 86-0284, the mishap aircraft (Tab V-1 Pg. 5). The MA had a recent history of radar problems that could potentially present a problem to completion of ARGOS 02's mission qualification training (Tab H-2). During preflight the mishap pilot paused at the rear of the engine because he "had a feeling" something was wrong with the turbines. Both the pilot and crew chief examined the rear of the engine , but found nothing wrong (V-1 Pg. 5). The rest of preflight, engine start, and takeoff on the Mishap Aircraft (MA) was otherwise uneventful except for a brief problem with fuel transfer between tanks which was resolved prior to takeoff (Tab V-1 Pg. 6).

d. Summary of Accident.

The mishap aircraft departed Cannon AFB at 0755L MDT (1355Z) on 12 July 1999 (Tab K3-4). All flight pilots stated the weather was clear (VMC) as forecast with only scattered clouds (Tabs V1, V2, V3, V4). Surface weather observations and satellite imagery valid at 0750L on the date of the mishap confirm these observations (Tab W-2, W-7). The flight proceeded southeast to the BRONCO Military Operating Area (MOA) located 80 nautical miles SE of Cannon AFB, at an air traffic control assigned block altitude of 15,000ft-16,000ft MSL (Tabs V-1, V-2, V-3, V-4). The Heads-Up Display (HUD) video tape indicates the flight entered the MOA at approximately 0803L, performed a 90/180 degree G-awareness maneuver, and then separated (Tab V-1 Pg. 6). ARGOS 03 (the MP) and ARGOS 04 flew to the eastern portion of the MOA to serve as the Red Air element for the MQT activity. The flight began their first intercept at 0807L and completed four "two-versus-two" intercepts. The MP noticed no aircraft problems or instrument anomalies during this period (Tab V-1 Pg. 7). At approximately 0826:15L (time displayed on cockpit video) while proceeding back to the eastern set-up point in the MOA (Tab V-1 Pg. 7), ARGOS 03 received a warning message on his multifunction display and then reported an engine failure and flameout while at an altitude of 16,200'MSL (13,160' AGL) (Tab N-2, and video of HUD). ARGOS 04 reported seeing a large orange-red fireball and plume of smoke at the rear of the MA just prior to the MP's notification that there was trouble (Tab V-2 Pg. 1). The MP accomplished the critical action procedures for an engine failure and attempted two airstarts (Tabs V-1 Pgs. 7-9, O-12). The MP continued flying in the general direction of Hobbs/Lea County Airport, New Mexico, an available emergency airfield (Tab R-3). The MP received altitude and navigation assistance from his wingman, ARGOS 04, as he continued emergency procedures (Tab N-1 through N-4, V-2). ARGOS 01 made contact with Hobbs/Lea County Airport on guard frequency (243.0mhz) and relayed the nature of the emergency (Tab N-2 through N-5, V-4). The airstarts were unsuccessful and the MP stated the engine appeared to have "seized" (Tab N-4). The MP noted his flight conditions (airspeed, altitude, and remaining distance to Hobbs/Lea County Airport) would not allow a successful glide to the emergency airfield (Tab N-4, V-1 Pgs. 8-9). The MP turned the MA towards an uninhabited area in preparation for ejection. At 5,500' MSL, the MP accomplished pre-ejection procedures, began a zoom maneuver, and initiated a successful ejection with only minor injury (Tab V-1, V-2). A review of the HUD video recording and shows ejection was initiated approximately 4 minutes 45 seconds after initial warning indications of engine failure (04:45 elapsed from the last actual displayed time on the HUD).

e. Impact.

After pilot ejection, aircraft S/N 86-0284 continued in a descent for approximately 20 seconds and impacted a private pasture, sliding approximately 120 yards before coming to rest on County Road 73 (coordinates N32-53.67 W103-08.63) 85nm SSE of Cannon AFB, NM (Tab R-3, Z-8 through Z-16). The MA was traveling at 140 knots (Tab O-5) in a 6 degree nose high attitude (Tab O-13) on impact. The engine was not rotating at the time of impact (Tab O-12). The MA leaked JP-8 onto the ground according to on-scene personnel (Tab O-31 through O-34 S-3, Z-8 through Z-11). The on-board hydrazine canisters were partially depleted during start of the Emergency Power Unit (EPU) and were later removed by responding fuels personnel from Cannon AFB (Tab O-34). The New Mexico State Police Hazardous Materials Emergency Response Report indicated approximately 3,700lbs (600 gallons) of JP-8 leaked into the ground at the scene (Tab O-31).

f. Life Support Equip, Egress, and Survival.

The MP initiated ejection at 5,500 feet MSL following a zoom maneuver. ARGOS 04 reported seeing the ejection seat leave the rails (Tab V-2 Pg. 2). The ejection system functioned as designed with man-seat separation occurring as expected for an ejection within the performance envelope of the aircraft at the time of the mishap (Tab J-141 through J-144). A review of inspection records for the Advanced Concept Ejection Seat (ACES) II, all egress components, and the seat-kit survival gear installed in the MA indicated all inspections and TCTOs were current (Tabs U-26 through U-40). Personal life support equipment inspections were current (Tab CC). The emergency locator transmitter (ELT) beacon functioned for approximately seven seconds after activation (Tab J-145). Post mishap failure analysis of the ELT beacon determined the ELT failed due to battery depletion even though the battery had not exceeded its designed shelf-life. The failure analysis report indicated early depletion is not uncommon for batteries consistently exposed to high aircraft cockpit temperatures like those found in New Mexico (Tab J-145, J-146). Additionally, the analysis identified cracks on the top of the ELT battery. These cracks were consistent with both shrinkage of sealing compound and ground impact induced cracks (Tab J145, J-146). The ELT failure did not have an adverse impact on the search and rescue effort due to the wingman's (ARGOS 04) visual tally on the MP during parachute descent and landing.

g. Search and Rescue.

Starting a stopwatch from the last displayed clock time on the cockpit video until start of ejection indicates the MP ejected at approximately 0830:32L. ARGOS 04 maintained a visual tally on the MP after ejection (Tab V-2). Once on the ground, the MP communicated with the flight using his survival radio (Tab V-1, V-2). ARGOS 04 noted the coordinates of the MP and passed them to the flight leader (ARGOS 01) (Tab V-2). ARGOS 01 passed the coordinates of the downed airman to the supervisor of flying at Cannon AFB, Hobbs/Lea County Airport tower, and Ft. Worth Air Traffic Control Center for relay to civilian authorities (Tab V-4). The Hobbs Fire Department arrived on-scene at 0848L with three personnel, one a paramedic (Tab 0-26, O-27). The MP refused treatment for minor injuries and transport to a hospital (Tab O-27). After contact with the MP, the local response team cordoned off the crash site (Tab O-31). A convoy of first responders arrived from Cannon AFB at 1046L and transported the pilot back to the Cannon AFB Medical Treatment Facility, at 1149L (Tab O-22).

## 5. MAINTENANCE

### a. Forms Documentation.

A review of the aircraft AFTO Form 781 series, Core Automated Maintenance System (CAMS) and maintenance logs revealed no documentation discrepancies. The review of the active AFTO Form 781 series for the MA did not reveal any evidence of unresolved maintenance discrepancies (Tab U-2 through U-17) that contributed to this accident. The combined review of documented history revealed no recurring maintenance abnormalities that contributed to this mishap. The previous 30 days CAMS and aircraft historical files divulged no negative trends (Tab H-2). The status of the MA Time Compliance Technical Orders (TCTO) (Tab H-4) and of the mishap engine (ME) TCTO (Tab H-9) that are relevant to this accident were complied with.

### b. Inspections.

All scheduled inspections on the MA (Tabs D-2 and U-2) and ME (Tabs D-2 and H-8) were completed on time. The 31 Mar 99, 100 hour borescope inspection in the HPT area was completed using technical order 1F-16C-2-70FI-00-11 Tables 10-17 and 10-17.1 (Tab BB-3 through BB-29 ).

### c. Maintenance Procedures.

A review of the maintenance procedural, practice, and performance indicators show nothing that appears related to the accident. The active AFTO 781's forms indicated that maintenance, preflight and servicing actions performed on the MA prior to the accident were not related to the accident (Tab H-2 through H-5, U-2 through U-17).

### d. Maintenance Personnel and Supervision:

All maintenance personnel involved with the MA and ME on the flight line and in the support shops were qualified or under direct supervision of qualified trainers. A review of AF Form 623 (Individual Training Record), AF Form 797 (Job Qualification Standard Continuation/Command JQS), and CAMS qualification reports confirmed qualified personnel were performing the required maintenance actions (Tabs DD-46 through DD-55). Training for relevant maintenance personnel appeared adequate, coming from formal technical schools, Field Training Detachments (FTD), local training programs and On-The-Job Training (OJT). The AIB's review of maintenance supervision indicated supervision was activity involved in the training process. While experience levels were low in some areas, the eagerness to learn and do the job right was evident to the board. 27 CRS production and deployment taskings are consistent with other ACC units (Tab DD-61).

### e. Fuel, Hydraulic and Oil Inspection Analysis.

The pre and post oil carts (Tabs J-138, J-139, J-140) Joint Oil Analysis Program (JOAP) analysis results were code "A", or normal, as defined in T.O. 33-1-37-2 Appendix G (Tab BB-33). The JOAP history on the ME has been code "A" (Tab U-18). Additionally the chip detector inspection using the SEM/EDX machine showed no evidence of metallic debris present. (Tab U-19 , U-20).

The Hydraulic cart analysis (Tab J-114) and visual inspection (Tab J-138) results were normal.

The JP-8 samples taken from the fuel trucks that serviced the MA prior to mishap met USAF specifications . Truck 97L00134 was used on 9 Jul 99 (Tab DD-43). Truck 96L00165 was used on 8 Jul 99 (Tab DD-45). Not all of the post-mishap JP-8 fuel sample taken met specifications. The passed samples are under the following Tabs (Tab J-117 through J-120, J-123, J-124, J-127 through J-132, J-134 through J-137). The fuel in the right center aircraft tank (Tab J-121, J-122) and storage tank 394 (Tab J-125, J-126) initially failed specifications for thermal stability, but retest was performed with satisfactory results (Tabs DD-40, DD-41).

### f. Unscheduled Maintenance.

On 8 July 1999, the Augmentor Fuel Control was removed for leaking beyond T.O. limits and was replaced (Tab U-21). An engine run was performed after the Augmentor Fuel Control was replaced. The engine run revealed no discrepancies (Tab U-22). All other unscheduled maintenance performed since the 10 May 1999 aircraft Phase Inspection and 31 March 1999 100 hour engine borescope inspection had no bearing on the mishap.

## 6. AIRCRAFT AND AIRFRAME

### a. Condition of systems.

The pilot reported all aircraft systems and flight controls were working normally up until the engine failure (Tabs O-12 through O-19, V-1). The emergency power unit functioned normally after engine failure and provided the required electrical back-up power during the emergency (Tab V-1). The aircraft engine (model F110-GE-100, S/N 509518) was not running upon impact as noted by the Crash Survivable Flight Data Recorder data and examination of the engine wreckage. (Tabs J-2, O-12). The aircraft impacted a field and remained mostly intact leaving investigators an unusual amount of evidence relative to other aircraft crashes. The General Electric engine was still attached inside the fuselage when the interim safety board arrived. Initial on-scene inspection revealed the engine exhaust nozzle sustained damage from the four o'clock to the eight o'clock position. Two exhaust nozzle outer flaps were separated from their front mounts. The crushed aircraft inlet obstructed the view of the engine inlet. The engine accessory gearbox along with the attaching components were stripped from the bottom of the engine and scattered about the crash sight. The aircraft was transported back to Cannon AFB were the engine was removed for disassembly and investigation (Tab J-2).

Disassembly and investigation of the engine revealed the following: All inlet guide vanes and struts were intact, with minor impact damage from the five o'clock to the seven o'clock position. The fan assembly was intact and showed no significant airfoil damage. The lower fan case sustained minimal impact damage. There was no damage to the upper fan stator case. The fan frame aft flange was cracked at the six o'clock position due to impact with the ground. Both the upper and lower T2.5 sensors were intact and free of significant damage. The outer fan ducts were bent and buckled due to the impact, with the Variable Stator Vane (VSV) actuators and the VSV torque tubes in place. The high pressure compressor had no significant airfoil damage noted on stages 1 through 9. The combustor diffuser nozzle (CDN) assembly sustained some damage due to impact. The T4B pyrometer was broken from its mount on the lower outer fan duct due to impact, but the sight tube remained in the CDN case. There was no significant damage to the fuel manifolds, fuel nozzles or the combustor. The turbine area of the engine showed signs of distress. The High Pressure Turbine (HPT) nozzle leading edges appeared to be serviceable, but the trailing edges had chipped areas and deposited material on them. The HPT blade retainers, both forward and aft appeared serviceable. The HPT blades were burned away at ¼ to ½ inch above their platforms. Two of the HPT blades had liberated above the inner dovetail approximately 170 degrees a part. A third blade exhibited cracking in the lower dovetail pressure side mating surface. All other HPT blade dovetails were fluorescent penetrant inspected (FPI) and found to be free of cracks. The HPT disk appeared to be in serviceable condition except for three disk post partial outer tang liberation's. One of the liberated pieces was found during disassembly. The HPT shroud exhibited damage that would be expected with two HPT blade releases. Six shroud segments were completely destroyed where the blade impacted. Several other shrouds had dime-size holes in them. The remainder of the shroud segments were burnt and had metal splatter from the HPT blades. One "C" Clip was found loose and liberated completely during the Low Pressure Turbine (LPT) removal. The LPT stage one nozzle airfoils were intact with minor damage and debris deposited on them from the missing HPT blades. All of the LPT stage 1 turbine rotor blades were intact but have heavy scoring and missing material on the leading edge from the HPT blade release. The inboard side of the tip shroud has a large amount of HPT material build up. The LPT stage 2 blades exhibit the same damage as the stage one blades. The rest of the LPT assembly was not disassembled so the stage 2 LPT nozzle was not inspected. All of the turnbuckles were broken out of the turbine frame, and the aft flange was bent with several cracks in the outer shroud. The augmentor assembly, spray bars, and flame holder were buckled inward from 5 o'clock to 7 o'clock position. The exhaust nozzle duct outer liner was cracked 350 degrees aft of the A8 actuators. Both lower A8 actuators along with the A8 linear variable differential transducer (LVDT) were broken away from their mounts. The exhaust nozzle flaps and seals were heavily damaged from the 4 o'clock to 8 o'clock positions from impact. The number one, four, and five bearings were exposed for inspection and showed no signs of failure or distress. The number two and three bearings were borescoped with no anomalies noted. The core rotated freely indicating that there was no damage to the number three bearing. The accessory gearbox and externally mounted components all sustained heavy damage from the crash. The gearbox was broken into pieces, with only a few fragments recovered. The main engine control (MEC) and main fuel pump (MFP) were still coupled together, but had sustained impact damage. The lube and scavenge pump was still attached to a portion of the gearbox, but the hydraulic pump had been broken off. The augmentor fuel pump, engine boost pump, and the A/C generator were still attached to their portion of the gearbox and all appeared to be in good condition. The augmentor fan temperature control (AFTC) cover, had been ripped off during the crash, exposing its internal electric modules. The engine monitoring system processor was completely destroyed. Both the oil tank and fuel oil cooler were completely destroyed (Tabs J-2 through J-4).

b. Testing

Several aircraft and engine parts were sent for testing and evaluation The parts sent and the results of the tests conducted are listed below.

High Pressure Turbine Blades: All remaining HPT blades were sent to the General Electric Aircraft Engines Materials and Process Engineering Department. Testing was conducted on the pieces of the blade dovetails (blades No.1 & 39) that remained in the disk post slots. The blades were confirmed to be manufactured from DSR 80H material as specified. Scanning Electric Microscope (SEM) examination of the fracture surfaces revealed that the cracking had initiated in the minimum neck area of the blade dovetails and the failures were consistent with a tensile overload or low temperature rupture failure. (Tab J-6 through J-8)

High Pressure Turbine Disk: The HPT disk was also sent to General Electric Aircraft Engines Materials and Process Engineering Department for testing. The mishap HPT disk was manufactured by General Electric. The high pressure turbine disk along with the recovered piece of the No. 8 post were tested. The disk was confirmed to be the material specified, Rene' 95 alloy. Further tests were conducted using a Scanning Electric Microscope (SEM). The testing revealed that separation of the outer portions of the disk posts were the result of multiple origin fatigue cracks that initiated along the inboard edge of the outer dovetail serration pressure face contact area. Measurements of the disk post pressure faces were taken on several of the disk posts. These measurements indicated some of the pressure face dimensions did not meet the Min/Max Stack requirements. (Tab J-50 through J-97)

High Pressure Turbine Shroud: The HPT shroud and "C" Clip were sent to General Electric Engines for testing. Evaluation of the HPT shroud assembly indicated that the heaviest damage to the shrouds and shroud support occurred in the 8 o'clock location. This is the area that is believed to be the impact area of the liberated HPT blades. The examination concluded that wear patterns present on the aft face of the "C" Clip were typical of normal contact and molten metal spatter patterns did not support the premise that the clip had disengaged prior to the non-recoverable in flight shut down (NRIFSD) event. (Tab J-98 through J-113)

T4B Pyrometer: The T4B pyrometer was sent to the Oklahoma City Air Logistics Center (OC-ALC) at Tinker AFB for investigation. Testing indicated that the room temperature voltage test was within specified Technical Order limits. The pyrometer did not respond to heat input test; however, it was concluded that this was due to the damaged housing. The pyrometer was subjected to two vibration tests. One test was conducted at room temperature and one after the pyrometer was subjected to a heat soak at 240 degrees F for one hour. The pyrometer passed both tests. (Tab O-10)

Fuel Nozzles: The fuel nozzles (20 each) were also sent to OC-ALC at Tinker AFB for investigation. One fuel nozzle (position #11) was bent from impact and could not be tested. One fuel nozzle (position #20) had low flow. One fuel nozzle (position #10) had an improper spray angle and low pressure decay. The remaining fuel nozzles were within Technical Order limits. (Tab O-11)

Panel Switches: The Fuel Master Feed Panel (P/N 16E1077) and the Engine Jet Start Panel (P/N 16F4459) were sent to the Materials Integrity Branch at Wright-Patterson AFB (AFRL/MLSA) for an evaluation of aircraft switch positions. The evaluation concluded aircraft impact and break-up could account for the position of switches on the subject panels. (Tab O-39 through O-53).

Emergency Locator Beacon Assembly: Based on pilots reporting the emergency locator transmitter worked for only a few seconds, the entire beacon assembly was sent to the 311 HSW/YACL, Brooks AFB. An evaluation was requested on observed cracks and the reason for transmission failure. Brooks AFB determined depleted batteries caused the transmission failure. Case cracks were attributed to ground impact and cracks in materials used for sealing during the manufacturing process (Tabs J-145, J-146)

## 7. WEATHER

### a. Forecast Weather.

The forecast weather for all Cannon ranges, including the Bronco MOA, for 0750L on 12 July 99 was for scattered clouds at 25,000 ft and 7 miles visibility. Winds were forecast to be 160 degrees at 10 knots from the surface to 10,000 ft with an altimeter setting of 30.32 inches. (Tab K6)

### b. Observed Weather.

Surface weather observations and satellite imagery for the Bronco MOA valid at 1350Z (0750L) on the date of the incident indicated scattered clouds at 15,000 ft with unrestricted visibility (Tab W-2). Winds at 5,000 ft were 170 degrees at 10 knots with a temperature of 18C. Surface winds reported by Hobbs-Lea County Airport (KHOB) varied between 70-100 degrees at 5-8 knots with an altimeter setting between 30.28 and 30.30 inches during the period of mishap (Tab W-6). Satellite imagery confirms no significant cloud cover. (Tab W-7).

### c. Space Environment.

Not applicable.

### d. Conclusions.

A thorough review of the weather data noted no factors contributing to the mishap. The mishap element remained in visual meteorological conditions (VMC) and in visual contact with the ground throughout the entire mishap sequence (Tabs V1, V2, V3, V4).

## 8. CREW QUALIFICATIONS

The MP is on current Aeronautical Orders (Tab T-1). A thorough review of the mishap pilot's Flight Evaluation Folder (Tab T-4, T-5), F-16C Grade book, and Flying History noted nothing that could have contributed to the mishap. The mishap pilot recently (30 Jun) completed Flight Lead Upgrade (FLUG) training and has 667.4 flying hours with 386.5 primary hours in the F-16, including 12 combat hours (Tab G-2 through G-21).

| Period | Hours | Sorties |
|---|---|---|
| 30 days | 6.4 | 5 |
| 60 days | 18.6 | 14 |
| 90 days | 23.2 | 18 |

## 9. MEDICAL

### a. Qualifications.

A thorough review of the MP's medical record demonstrated the pilot was medically qualified to perform all flying duties. (Tab X-2).

### b. Health.

The MP was not experiencing any illness or sleep deprivation nor was he taking any medications at the time of the mishap (Tab X-2).

### c. Toxicology.

Toxicology specimens from the MP contained no alcohol, elevated carbon monoxide, or illegal substances (Tab X-3).

### d. Lifestyle.

There is no evidence that unusual habits, behavior, or stress on the part of the MP contributed to the mishap (Tab X-2).

### e. Crew Rest and Crew Duty Time.

The MP appropriately adhered to all crew rest and crew duty parameters and was rested. There were no significant stress factors affecting his ability to perform the mission (Tab V-1,X-2).

## 10. OPERATIONS AND SUPERVISION

### a. Operations.

Operations tempo in the 523rd Fighter Squadron is high, but consistent with other Air Combat Command active duty F-16C units. OPTEMPO was not a factor in the mishap.

### b. Supervision.

The Accident Investigation Board's review shows squadron supervision complied with all applicable regulations and directives concerning the conduct of the flight and is not considered a factor in the mishap.

## 11. HUMAN FACTORS ANALYSIS.

There is no evidence that human factors contributed to or were causal to this mishap (Tabs V-1 through V-10, X-2 through X-8).

## 12. GOVERNING DIRECTIVES AND PUBLICATIONS

### a. Primary Operations Directives and Publications.

*AFI 11-202, Volume 1, Aircrew Training*
*AFI 11-202, Volume 3, General Flight Rules*
*AFI 11-401, Flight Management*
*AFI 11-2F-16 Vol 1, F-16 Aircrew Training*
*MCI 11F-16, Volume 3, Pilot Operational Procedures, F-16*
*TO 1F-16C-1*

### b. Maintenance Directives and Publications.

*T.O. 1F-16C-2-70FI-00-11, Fault Isolation -- Power Plant*
*T.O. 33-1-37-2, Joint Oil Analysis Program Manual*
*T.O. 1F-16C-6-11, Scheduled Inspection and Maintenance Requirements*
*T.O. 2J-F110-4, Illustrated Parts Breakdown F-110-GE100 Turbofan Engine*
*AFI 21-101, Maintenance Management of Aircraft*

### c. Known or Suspected Deviations from Directives or Publications.

There were no known or suspected deviations from directives or publications that were factors in this mishap.

## 13. NEWS MEDIA INVOLVEMENT

The 27th Fighter Wing Public Affairs Office at Cannon AFB, NM provided the official USAF News Release and handled media inquiries about the mishap. Media interest was low with mostly local media covering the story. Print media stories appeared in the Clovis News Journal, Albuquerque Journal, Lubbock Avalanche-Journal, The Lovington Daily, and Amarillo Daily News (Tab EE). The local CBS affiliate broadcast a brief story that included video footage of the crash site taken from a helicopter. A VHS video tape copy of the broadcast is part of the official archive of this investigation.

## 14. ADDITIONAL AREAS OF CONCERN

No evidence surfaced during the course of this investigation that suggested any internal or external radio frequency propagation anomalies or electromagnetic interference (EMI) influences were causal or factors contributing to the mishap.

8 September 1999

FREDERICK R. STRAIN, Colonel, USAF
President, Accident Investigation Board

# STATEMENT OF OPINION

## F-16C ACCIDENT
## 12 July 1999

1. *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 may not be considered as evidence in any civil or criminal proceeding arising from an aircraft 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.*

2. OPINION SUMMARY: The primary cause of the mishap supported by clear and convincing evidence, was a non-recoverable in-flight engine shutdown caused by a catastrophic failure in the High Pressure Turbine (HPT) assembly. The HPT failed when two HPT blades separated due to fatigue. Beyond gliding distance to the nearest emergency airfield, the pilot was forced to eject. Convincing evidence suggests the separation of portions of the HPT dovetail disk posts in the upper pressure face area caused the fatigue failure of the HPT blades in the minimum neck area and eventual blade separation. A casual factor in separation of pieces from the dovetail disk posts were pressure face surface dimensions that exceeded the maximum drawing stack specifications potentially due to disk deformation after high Total Accumulated Cycles.

3. DISCUSSION OF OPINION: The aircraft functioned normally until the mishap pilot experienced a large explosion, violent lurch of the aircraft, and subsequent engine failure. ARGOS 04, the wingman, reported seeing a large orange-red fireball and black smoke emanating from the rear of the mishap aircraft at the same time. These reports are consistent with the internal engine damage observed during disassembly at Cannon AFB, New Mexico. The post mishap engine tear-down revealed two missing HPT blades (P/N 1441M54P01), severe damage to the shroud surrounding the blade assembly, HPT blades that had burned/melted down, a loose shroud retaining clip (P/N 9523M21P01, commonly referred to as a c-clip), and molten metal spatter in both the HPT area and on the Low Pressure Turbine blades downstream of the HPT (Tabs J-2, J-3).

The last required inspection on engine S/N 509518 was a 100 hour borescope inspection accomplished on 31 March 1999 (Tabs D-2, U-23), 85.8 flight hours prior to the mishap (Tab H-8). This inspection was directed by T.O. 1F-16CG-6-11. The inspection revealed no defects or discrepancies outside of technical order tolerances on those areas examined (Tab U-23)

The initial post-mishap engine analysis suggested failure within the HPT section of the engine was the cause of the engine shutdown. The HPT disk, blades, and loose c-clip were sent to General Electric for material testing and failure evaluation (Tabs J-6, J-50, J-98). Evaluation of the HPT blades revealed no material or manufacturing defects and the blades were all manufactured from the required DSR 80H alloy. Two blades (labeled as Nos. 1 & 39) at roughly opposing locations on the disk were missing from their respective disk slots. These blades separated at what is called the minimum neck area, an area towards the bottom of the blade dovetail that mates with the HPT disk (Tab DD-39). A third blade (labeled as No. 8) exhibited a severe crack in the same area and was on the verge of failure (Tab J-8, J-25). Testing indicated these blades failed due to fatigue (attributed to high alternating stress and low frequency loading propagation) and tensile overload. Both forms of failure exhibit unique characteristics when scanned by an electron microscope. All remaining blades were Fluorescent Penetrant Inspection (FPI) tested and 20 blades were found to have surface cracks caused by tensile overload or low temperature rupture, not fatigue (Tab J-9).

The HPT disk was tested, measured, and evaluated. The disk was manufactured from the required RENE 95 alloy and exhibited no material or manufacturing deficiency (Tab J-52, J-56). The disk measured within tolerances for diameter (Tab O-54). Additional measurements of the pressure face surfaces, the machined contact points between the disk posts and blades, indicated these surfaces were not parallel in all cases as required by the drawing. Measurements indicated some of the machined faces exceeded the maximum stack dimensions permitted by the drawing (Tab O-55). This resulted in what can best be described as a "wavy" contact surface, when the desired goal is a perfectly flat contact area. On the top of three disk posts adjacent to separated blades Nos. 1 & 39 and cracked blade No. 8 (the blade on the verge of separation), large crescent-shaped pieces of material were missing (Tabs J-51, J-58, J-59, J-60). One of these missing chunks was recovered during engine disassembly (Tab J-3).

The loose C-clip was also evaluated along with the adjacent retaining clip in the shroud assembly. C-clips are used to retain shrouds around the perimeter of the HPT assembly.

Given the circumstances and evidence, the board investigated the following as potential causes or contributing factors to the engine failure:

- Pilot error
- Substandard JP-8 Jet Fuel
- Failure by engine shop personnel or the OC-ALC to properly assemble engine S/N 509518 during the last major maintenance or detect advanced signs of failure in the High Pressure Turbine area during required borescope inspections.
- Internal or external foreign object damage originating forward of the High Pressure Turbine Area.
- A loose HPT shroud retaining clip (c-clip) that permitted a shroud to fall slightly and contact the HPT blades.
- Substandard material used in the manufacture of the HPT blades or HPT disk
- Failure along the pressure face contact surfaces of the HPT dovetail disk posts leading to fatigue in the HPT blade minimum neck area.

The board determined pilot error was not a factor in this mishap. The pilot was fully trained, adhered to all directives governing the flight, and accomplished all emergency procedures expected of him during the mishap.

Initial testing of fuel in the mishap aircraft indicated the fuel in the right center tank did not meet USAF specifications for JP-8 jet fuel. Specifically, it failed the thermal stability test (Tab J-121, J-122). Testing of the base fuel storage tanks revealed one tank of fuel which also failed the same test for thermal stability (Tab J-125, J-126). The board initially reviewed whether sub-standard fuel could have caused the catastrophic damage seen in the High Pressure Turbine area. The board also had questions about how substandard fuel would get into only one aircraft fuel tank and not the others given the F-16C is fueled at a single point. Subsequent to our initial questions, the board received documentation showing that re-testing of both fuel samples indicated the fuel in the aircraft and base storage tanks met all specifications (Tabs DD-40, DD-41). The initial failures were attributed to problems in handling and transport of the first fuel samples. Substandard fuel was therefore eliminated as a cause of factor of engine failure.

All inspection and maintenance records for the mishap engine were reviewed by qualified board members. There was no evidence during engine disassembly that any engine components were missing or improperly installed by OC-ALC or the 27 CRS. The engine had been installed in four different aircraft since the last major depot overhaul and had performed as required without major failure up until the day of the mishap. A review of training and certification records indicated that all personnel performing inspections and/or maintenance actions on the subject engine were fully qualified to perform these duties (Tab DD-46 through DD-55). A review of engine shop documentation and discussions with personnel gave the board a high degree of confidence that all maintenance and inspection discrepancies are thoroughly documented and addressed when discovered. 27 CRS personnel interviewed during the course of the investigation indicated that the only general problems noted during borescope inspections of the HPT areas on assigned engines have been cracks due to heat in some areas of the HPT; however, these cracks have usually been within technical order tolerances and replaced if out of tolerance (Tab V-9, V-10). The board was confident that maintenance or inspection procedures were not factors in this mishap.

External Foreign Object Damage (FOD) was ruled out as casual to engine failure. No damage to the front stages of the engine was noted during engine disassembly that was not attributed to ground impact (Tab J-2, J-3). Additionally, there were no indications of missing internal components upstream of the HPT area that would have intruded into the HPT assembly area causing failure.

The board spent a good deal of time examining the data surrounding the loose C-clip (shroud retaining clip) discovered during engine disassembly. There have been instances where the c-clip has come loose or "backed-off" the shroud and aft support shroud rail (Tab DD-56). This allows a shroud to partially lower into the path of an HPT blade. The board saw one such example on an actual engine at the 27 CRS at the mishap base. General Electric evaluated the loose c-clip and the clip adjacent to the suspect clip. Testing and examination revealed that both the presence and absence of molten metal spatter on different portions of the loose clip indicated that at least a portion of the clip was affixed to the shroud and aft support shroud rail at the time of HPT failure (Tab J-100). This data, together with the fact that the loose clip was in the area of greatest damage (the impact area of the separating blades) and witness marks on the clip indicated one-time contact with another component during impact, led the board to agree with General Electric that that the c-clip came loose during an impact event and was not casual to HPT blade failure (Tab J-100). OC-ALC engineers supported this conclusion (Tab DD-38).

Failures of either the HPT blades or disk due to the use of substandard materials was not supported by the evidence. Metallurgical analysis revealed both components were manufactured from the required alloys and there were no irregularities observed in the granular structures of either component (Tab J-7, J-52).

Following elimination of other causes the board focused on why the HPT blades failed in the minimum neck area. Four anomalies noted during engine tear-down and subsequent testing and measuring were examined: 1) separation of portions of the HPT disk posts adjacent to the failed blades, 2) measurements that indicated pressure face surfaces of HPT disk posts exceeded maximum stack dimensions according to drawings, i.e. machined mating surfaces were not flat and parallel as desired, 3) damage to HPT disk platforms and damper retention tangs in a cavity above the failed disk posts, and 4) indications of fatigue and tensile overload failure in the HPT blade minimum neck area.

The board queried the USAF chief engineer for the GE F100 engines at the Oklahoma City Air Logistics Center (OC-ALC). We requested any cases of HPT dovetail disk post separation in the USAF historical data base for P/N 1385M23P03 disks. The board received information on two previous cases of HPT disk post failures, one in 1996 (Tab DD-2) and another in 1997 (Tab DD-12). In both cases, pictures of the disk post failures appear identical to those found on the mishap HPT disk. Both cases indicated a crescent moon-shaped piece of missing material at the top of the post with the failure origin along the upper pressure face contact surface. In one case, the disk post failure was found during depot maintenance on the engine. In the second instance, the damage was discovered during a local inspection. Engineers at the time attributed the start of both failures to "fretting," a particular rubbing wear pattern, along the pressure face which eventually led to fatigue cracking and separation (Tab DD-3, DD-16). It should be noted that it is not always possible to get a group of engineers to agree whether the characteristics of fretting are present on a particular surface. A USAF metallurgist and a mishap investigator at OC-ALC examined the data and photos from the metallurgical investigation of the current mishap disk. The metallurgist told the accident board propulsion expert that he believed fretting was evident on the pressure face surfaces of the mishap disk even though General Electric engineers accomplishing the tests for the USAF did not detect "surface damage attributed to fretting" (Tab J-52). The OC-ALC investigator stated that given the uniform locations and number of origin sites found, "fretting or a similar not fully understood phenomenon would be the probable cause"(Tab DD-37).

If the board could not conclusively point to fretting along the pressure face as the genesis of failure in the disk post surface, then we had to ask if there were any other anomalies or phenomena in this area. Additional dimensional evaluations of the HPT disk post and HPT blade pressure faces were accomplished by General Electric under contract to the USAF (Tab O-54, O-55). GE measured pressure face surfaces at three points on several posts to determine whether surfaces were flat and parallel to each other, characteristics important to the proper mounting of a blade in its respective slot. Surfaces on the blades were found to be within drawing specifications except for one point (Tab O-55). This was not the case for some surfaces on the HPT disk posts. Measurements indicated not all disk post pressure face surfaces were parallel or flat; some measurements exceeded the max stack drawing specification indicating some "waviness" of surfaces (Tab O-55). The testing lab also measured a new HPT disk and a second HPT disk that had approximately 3,000 TAC (Total Accumulated Cycles). Both of the reference disks were within drawing tolerances. These results are significant. Measurements taken in the 1997 disk post failure also indicated that the "fractured disk post did not meet the waviness requirement on one end (0.004) but it did meet the requirement on the other end (0.002)." (Tab DD-21) The board believes there is reasonable evidence to suggest that the observed dimensional anomalies (failure of waviness criteria) along the disk post pressure faces on the current mishap disk were factors in initiation of failure along the pressure face surface. No such measurements were taken of the disk mentioned in the 1996 report so a comparison of this data is not possible. The current mishap disk from engine S/N 509518 had 1541 TAC since overhaul and 5,988 TAC since new (Tab U-25). TAC of the 1996 and 1997 disks is unknown although the 1997 disk is noted as having 1247.0 hours of operating time (Tab DD-12). OC-ALC told the board that 9,000 TAC is the maximum life of an HPT disk. Disks are discarded at this point. OC-ALC also related that approximately five percent of HPT disks do not make it past 6,000 TAC due to failure of an eddy current inspection (a long duration non-destructive inspection to evaluate structural integrity) at this TAC point. The mishap disk is considered a relatively "high time" disk.

Damage found in the cavities above the failed disk posts and deformation of the HPT blade platforms (Tab J-37) is consistent with a chunk of disk post that broke off and remained in the cavity doing damage for a number of engine cycles. The evidence supporting this conclusion is that testing and examination of this area did not indicate witness marks consistent with "one time impact" in this area, rather damage was quite extensive (Tab J-8, J-37). Furthermore, once an engine begins rotating, centrifugal force would keep the loose piece pinned against the ceiling of the cavity. These facts suggest a condition where each time the engine was started, the loose piece rattled around the cavity at low RPM until it was flung against the blade platform from centrifugal force. Likewise, once the engine reached a low RPM after shutdown, the piece again began to rattle about in the cavity. It would seem reasonable to believe it took several low cycle events to achieve the level of damage seen within the cavity.

General Electric testing and evaluation of the failed blades indicated failure in the minimum neck area due to fatigue and tensile overload (Tab J-8). The board believes, and its opinion is supported by OC-ALC (Tab DD-38), that portions of the disk posts supporting the upper portion of the blade broke off sometime prior to blade failure. The loss of upper blade support placed an additional stress load on the lower support contact surfaces. Over several cycles, the min neck area of the blade was subjected to extra stress resulting in the observed fatigue and eventual failure in this area. This is supported by the fatigue marks seen in the blade min neck area (Tab J-14, J-15). Electron microscope examination revealed as many as 300-400 fatigue striations in one area where blade separation occurred (Tab J-9), again suggesting the events leading up to failure happened over a longer time period. Once the blade separated, catastrophic failure in the HPT section of the engine was assured.

It is a fact that HPT disks change dimension over time and tolerances are established for disk growth. Normal dimension checks of the mishap disk revealed such growth (Tab O-54). The board believes that high-time (high TAC) disks may also distort along the disk post pressure faces resulting in failure of the "waviness" criteria. Dimensional checks along the pressure faces are not required measurements during routine local inspections or at the 3,000 and 6,000 TAC inspections accomplished at the depot (OC-ALC). It was interesting to note that the new disk used for comparison had minimum deviation from the optimum pressure face dimensions, the 3,000 TAC comparison disk showed much greater deviation in these areas, and the 5,900 TAC mishap disk had measurements far exceeding specifications. The suggestion is that dimensional growth in this area may begin at some point between 3,000 and 6,000 TAC.

R. Strain

8 September 1999

FREDERICK R. STRAIN, Col, USAF
President, Accident Investigation Board

NUCLEAR REGULATORY COMMISSION

Docket No. ______ Official Exh. No. 14

In the matter of PFS

Staff ______ IDENTIFIED ✓

Applicant ______ RECEIVED ✓

Intervenor ______ REJECTED ______

Other Joint WITHDRAWN ______

DATE 4-11-02 Witness ______

Clerk L. Shindurling