

UNITED STATES AIR FORCE
AIRCRAFT ACCIDENT INVESTIGATION
BOARD REPORT



F-16CM, T/N 88-0518

**421ST FIGHTER SQUADRON
388TH FIGHTER WING
HILL AIR FORCE BASE, UTAH**



LOCATION: USCENCOM AOR DATE

OF ACCIDENT: 29 MARCH 2016

BOARD PRESIDENT:

COLONEL THOMAS N. JOHNSON

Conducted IAW Air Force Instruction 51-503



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

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9 NOV 2016

ACTION OF THE CONVENING AUTHORITY

The Report of the Accident Investigation Board, conducted under the provisions of AFI 51-503, that investigated the 29 March 2016 mishap involving F-16CM, T/N 88-0518, 421st Fighter Squadron, 388th Fighter Wing, Hill Air Force Base, Utah, complies with applicable regulatory and statutory guidance; on that basis it is approved.

//Signed//

JERRY D. HARRIS, JR.
Major General, USAF
Vice Commander

Agile Combat Power

**EXECUTIVE SUMMARY
UNITED STATES AIR FORCE
AIRCRAFT ACCIDENT INVESTIGATION**

**F-16CM, T/N 88-0518
USCENTCOM AOR
29 MARCH 2016**

On 29 March 2016, at 2027 local time, in the United States Central Command Area of Responsibility, the Mishap Aircraft (MA), an F-16CM, tail number 88-0518, assigned to the 421st Fighter Squadron, 388th Fighter Wing, Hill Air Force Base, Utah, suffered a hardware malfunction in the Mishap Engine (ME), resulting in an uncommanded engine rollback shortly after takeoff which triggered an unrecoverable compressor stall. The Mishap Pilot (MP) immediately executed a climb, ejected safely, and only sustained minor injuries. The MA, valued at \$25,335,314, was destroyed. Including other government property, the total government loss for this mishap is valued at \$29,076,216. In addition, there was some damage to non-DoD crops.

The mishap occurred on an alert scramble two-ship night flight. Just after takeoff, the MP simultaneously saw a giant explosion shoot out the front of the MA, heard loud grinding and two big thumps accompanied by significant vibration. At that moment, the MA was approximately 20' above the runway traveling at 200 knots. Recognizing a state of degraded thrust, the MP immediately initiated a climb. At 880' above the ground with a rapidly decreasing climb-rate and airspeed decreasing below 170 knots, the MP ejected. Despite being in full afterburner (maximum available thrust), the MA crashed eight seconds later, in a rural area, within a mile of the runway. After ejection, the MP landed safely suffering only minor injuries. There were no other injuries.

The Accident Investigation Board President found, by a preponderance of the evidence, the cause of the mishap to be material failure of at least one Stage 2 Low Pressure Turbine blade, which induced an unrecoverable compressor stall shortly after takeoff. This event rendered the ME incapable of providing necessary thrust to maintain continued flight.

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

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS	iii
SUMMARY OF FACTS.....	5
1. AUTHORITY AND PURPOSE	5
a. Authority	5
b. Purpose.....	5
2. ACCIDENT SUMMARY	5
3. BACKGROUND	5
a. Air Combat Command (ACC).....	6
b. Twelfth Air Force (12 AF).....	6
c. 388th Fighter Wing (388 FW).....	6
d. 388th Operations Group (388 OG)	6
e. 421st Fighter Squadron (421 FS)	6
f. F-16CM – Fighting Falcon	7
4. SEQUENCE OF EVENTS	7
a. Mission.....	7
b. Planning	7
c. Preflight.....	7
d. Summary of Accident – See Diagram 1 below	8
e. Impact.....	9
f. Egress and Aircrew Flight Equipment (AFE).....	9
g. Combat Search and Rescue (CSAR).....	10
h. Recovery of Remains	10
5. MAINTENANCE	10
a. Forms Documentation	10
b. Inspections	10
c. Maintenance Procedures.....	11
d. Maintenance Personnel and Supervision.....	11
e. Fuel, Hydraulic, and Oil Inspection Analyses	11
f. Unscheduled Maintenance.....	11
6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS.....	11
a. Structures and Systems.....	11
(1) Crash Survivable Flight Data Recorder	12
(2) Engine Analysis.....	12
b. Evaluation and Analysis.....	14
(1) Analysis 1	14
(2) Analysis 2	14
(3) Analysis 3	14
(4) Evaluation 1	14
(5) Evaluation 2.....	15
(6) Evaluation 3.....	15
(7) Evaluation 4.....	15
(8) Evaluation 5.....	15
7. WEATHER	15
a. Forecast Weather	15

b. Observed Weather	16
c. Space Environment.....	16
d. Operations	16
8. CREW QUALIFICATIONS	16
a. Mishap Pilot	16
9. MEDICAL	16
a. Qualifications	16
b. Health.....	17
c. Pathology.....	17
d. Lifestyle	17
e. Crew Rest and Crew Duty Time	17
10. OPERATIONS AND SUPERVISION	17
a. Operations	17
b. Supervision.....	18
11. HUMAN FACTORS ANALYSIS	18
12. GOVERNING DIRECTIVES AND PUBLICATIONS	18
(1) AFI 51-503, <i>Aerospace and Ground Accident Investigations</i> , 14 April 2015.....	18
(2) AFI 91-204, <i>Safety Investigations and Reports</i> , 12 February 2014, Corrective Actions Applied on 10 April 2015	18
(3) AFI 11-202, Volume 3, <i>General Flight Rules</i> , 7 November 2014	18
NOTICE: All directives and publications listed above are available digitally on the Air Force Departmental Publishing Office website at: http://www.e- publishing.af.mil	18
(1) DOD HFACS Version 7.0.....	18
(2) TO 1F-16CM-1, <i>Flight Manual USAF Series F-16C and F-16D</i> , 1 October 2015....	18
STATEMENT OF OPINION.....	19
1. Opinion Summary	19
2. Cause.....	21
3. Conclusion	21
INDEX OF TABS	22

ACRONYMS AND ABBREVIATIONS

12 AF	Twelfth Air Force	ISB	Interim Safety Board
388 FW	388th Fighter Wing	JHMCS	Joint Helmet Mounted Cueing System
421 FS	421st Fighter Squadron	JTAC	Joint Terminal Attack Controller
A8	Nozzle Area	KCAS	Knots Calibrated Airspeed
AB	Afterburner	L	Local Time
ACC	Air Combat Command	Lt Col	Lieutenant Colonel
ADCC	Assistant Dedicated Crew Chief	LM	Lockheed Martin Aeronautics Company
AF	Air Force	LOX	Liquid Oxygen
AFB	Air Force Base	LPT	Low Pressure Turbine
AFE	Air Flight Equipment	MA	Mishap Aircraft
AFI	Air Force Instruction	Maj	Major
AFIP	Air Force Institute of Pathology	MAJCOM	Major Command
AFM	Air Field Management	ME	Mishap Engine
AFTO	Air Force Technical Order	MEC	Mechanical Engine Control
AGL	Above Ground Level	MFF	Main Fuel Flow
AIB	Accident Investigation Board	MFL	Maintenance Fault List
ANG	Air National Guard	MFR	Memorandum for Record
AOA	Angle of Attack	Min	Minute
AOR	Area of Responsibility	MLG	Main Landing Gear
APG	All Purpose Guy	MP	Mishap Pilot
ATC	Air Traffic Control	MSL	Mean Sea Level
BPO	Basic Post Flight	MSgt	Master Sergeant
BM	Bird Man	MW	Mishap Wingman
CAPs	Critical Action Procedures	MX	Maintenance
Capt	Captain	NF	Fan Rotor Assembly RPM
Col	Colonel	NG	Compressor Rotor Assembly RPM
CSAR	Combat Search and Rescue	NM	Nautical Miles
CSFDR	Crash Survivable Flight Data Recorder	NOTAM	Notice to Airmen
CSMU	Crash Survivable Memory Unit	NVGs	Night Vision Goggles
DCC	Dedicated Crew Chief	OG	Operations Group
DEC	Digital Engine Control	Ops Tempo	Operations Tempo
Deg	degrees	ORM	Operational Risk Management
DFLCS	Digital Flight Control System	PHA	Preventive Health Assessment
DoD	Department of Defense	PLF	Parachute Landing Fall
E	Engine	PPE	Personal Protective Equipment
EBS	Engine Back Shop	PPH	Pounds per Hour
ECP	Entry Control Point	PR	Pre Flight
EOR	End of Runway	PS	Production Superintendent
EPLA	Throttle Angle	PS3	Compressor Discharge Pressure
F	Fahrenheit	PSI	Pounds per Square Inch
FL	Flight Lead	QA	Quality Assurance
FLCS	Flight Control System	QRF	Quick Reaction Force
FS	Fighter Squadron	ROZ	Restricted Operating Zone
FTIT	Fan Turbine Inlet Temperature	RPM	Revolutions per Minute
FW	Fighter Wing	SAU	Signal Acquisition Unit
GE	General Electric	Sec	Seconds
HFACS	Human Factors Analysis and Classification System	SEPT	Safety and Emergency Procedures Test
HUD	Heads Up Display	SIB	Safety Investigation Board
IAW	In Accordance With	SIM	Simulator
IMDS	Integrated Maintenance Data System	SME	Subject Matter Expert
IRC	Instrument Refresher Course	Sq In	Square Inches
		SrA	Senior Airman

SSgt	Staff Sergeant	USAF	United States Air Force
T4B	Compressor FTIT	USAFRC	United States Air Force Reserve Command
T56	Cockpit FTIT in degrees F	USCENTCOM	United States Central Command
TE	Tinker Engineering	UT	Utah
TH	Thru-Flight Inspection	WOW	Weight on Wheels
TO	Technical Order	WP	Witness Pilot
TCTO	Time Compliance Technical Order	Z	Zulu (Greenwich Mean Time)
T/N	Tail Number		

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 2 May 2016, Major General Jerry D. Harris Jr., Vice Commander, Air Combat Command (ACC), appointed Colonel Thomas N. Johnson to conduct an aircraft accident investigation of a mishap that occurred on 29 March 2016 involving an F-16CM, tail number 88-0518, in the United States Central Command (USCENTCOM) Area of Responsibility (AOR) (Tab Y-2 to Y-3). The accident investigation board (AIB) was conducted in accordance with (IAW) Air Force Instruction (AFI) 51-503, *Aerospace and Ground Accident Investigations*, at Hill Air Force Base (AFB), Utah (UT), 6-28 June 2016. The Board members included a Legal Advisor (Captain), Pilot Member (Major), Medical Member (Captain), Maintenance Member (Technical Sergeant), and Recorder (Staff Sergeant) (Tab Y-2 to Y-3). A jet mechanic, materials engineer, and two aerospace engineers were appointed as Subject Matter Experts (SMEs) (Tab Y-4 to Y-10).

b. Purpose

In accordance with AFI 51-503, *Aerospace and Ground Accident Investigations*, this accident investigation board conducted a legal investigation to inquire into all the facts and circumstances surrounding this Air Force aerospace accident, prepare a publicly releasable report, and obtain and preserve all available evidence for use in litigation, claims, disciplinary action, and adverse administrative action.

2. ACCIDENT SUMMARY

On 29 March 2016, at 2027 local time (L), in the USCENTCOM AOR, the Mishap Aircraft (MA), an F-16CM, tail number (T/N) 88-0518, assigned to the 421st Fighter Squadron, 388th Fighter Wing, Hill AFB, UT, suffered a hardware malfunction in the Mishap Engine (ME), resulting in an uncommanded engine rollback shortly after takeoff which triggered an unrecoverable compressor stall (Tab J-8). The Mishap Pilot (MP), 421st Fighter Squadron, 388th Fighter Wing, Hill AFB, UT, immediately executed a climb, ejected safely, and only sustained minor injuries (Tabs J-4, J-9, X-4). There were no other injuries. The MA, valued at \$25,335,314, was destroyed (Tab P-4). Including other government property, the total government loss for this mishap is valued at \$29,076,216 (Tab P-4). In addition, there was some damage to non-DoD land and crops.

3. BACKGROUND

The MA and MP both belonged to the 421st Fighter Squadron, 388th Operations Group, 388th Fighter Wing, 12th Air Force, Air Combat Command at Hill AFB, UT. (Tabs J-4, G-2, and CC-10).

a. Air Combat Command (ACC)

ACC, with its headquarters at Joint Base Langley-Eustis, Virginia, is the primary force provider of combat airpower to America’s warfighting commands (Tab CC-2). To support global implementation of national security strategy, ACC operates fighter, bomber, reconnaissance, battle-management, and electronic-combat aircraft (Tab CC-2). It also provides command control, communications, and intelligence systems, and conduct global information operations (Tab CC-2).



b. Twelfth Air Force (12 AF)

Twelfth Air Force is responsible for the combat readiness of ten active-duty wings and one direct reporting unit (Tab CC-9). The subordinate commands operate more than 800 aircraft with more than 64,000 uniformed and civilian Airmen (Tab CC-4). The command is also responsible for the operational readiness of thirteen 12 AF-gained wings and other units of the Air Force Reserve (USAFR) and Air National Guard (ANG) (Tab CC-9).



c. 388th Fighter Wing (388 FW)

The 388 FW, based at Hill AFB, UT, is equipped with F-16CM Fighting Falcons and a growing number of F-35A (Lightning II) Joint Strike Fighters (Tab CC-10). The wing’s primary mission is to maintain combat ready forces to deploy, employ, and sustain F-16s worldwide to fly, fight, and win any conflict (Tab CC-10). The wing has a storied history, as it has been involved in major campaigns since its activation at Gowen Field, Idaho, in 1942, for participation in World War II (Tab CC-10). Since September 11, 2001, the 388 FW has deployed its F-16s and supporting elements for active participation in Operations NOBLE EAGLE (homeland defense), IRAQI FREEDOM, ENDURING FREEDOM in Afghanistan, and, currently, FREEDOM’S SENTINEL (Tab CC-11).



d. 388th Operations Group (388 OG)

Three fighter squadrons form the 388 OG: 4th Fightin’ Fuujins, 421st Black Widows, and 34th Rude Rams (Tab CC-10). 388 OG remains responsible for weapons and tactics development, operational planning, flying training guidance, intelligence, flight scheduling, mobility, life support activities, and people management (Tab CC-10).



e. 421st Fighter Squadron (421 FS)

The 421 FS, assigned to the 388th Operations Group, 388 FW, Hill AFB, UT, is equipped with the F-16 Fighting Falcon (CC-14). Re-designated as the 421 FS on 1 November 1991, the squadron trains to deploy worldwide to conduct air superiority and precision strike missions (CC-14). The 421 FS has taken part in operations spanning the globe, from Vietnam to Saudi Arabia, Iraq, and Afghanistan. (Tab CC-14).



f. F-16CM – Fighting Falcon

The F-16CM Fighting Falcon (Viper) is a compact, multi-role fighter aircraft (CC-16). It is highly maneuverable and has proven itself in air-to-air combat and air-to-surface attack (CC-16). It provides a relatively low-cost, high performance weapon system for the United States and allied nations (CC-16). Since September 11, 2001, the F-16 has been a major component of the combat forces committed to the war on terrorism, flying thousands of sorties in support of Operations NOBLE EAGLE, ENDURING FREEDOM in Afghanistan, and IRAQI FREEDOM (Tab CC-17).



4. SEQUENCE OF EVENTS

a. Mission

The mission was an Air Tasking Order (ATO) night sortie in support of combat operations in the USCENTCOM AOR under the authority of the Combined Forces Air Component Commander.

b. Planning

The MP was the flight lead of a two-ship formation (Tab V-1.4). The Director of Operations, after a mass brief, initiated a crew change based on wingman experience, which moved the Mishap Wingman (MW) from a scheduled ATO formation into the alert flight (Tab V-1.4 and V-2.4). The MP and MW conducted a standard alert mission briefing in accordance with established procedures and guidelines (Tab V-1.4, V-2.4, and V-2.5). There was no squadron supervision in the individual flight brief; however, prior to the sortie the Operations Supervisor provided the MP and MW a standard step brief to update them on the field status, Notices to Airman (NOTAMS) and the current weather (Tabs R-69 and T-2).

c. Preflight

The MP attended a mass brief conducted by the operations supervisor (Tabs V-2.4, V-2.5, and R-69). Following the mass brief, the MP received an updated brief including NOTAMS, flight plans, field status, and weather (Tabs R-69 and T-2). The MP accomplished all applicable pre-flight aircraft inspections, including forms, and briefed the expected sortie (Tab V-1.4 and V-1.6 to 1.7). The MP and MW launched out of an alert status, but had more preflight notice than is normally available on most alert launches (Tab V-1.5). The weather forecast was favorable for a night sortie but with low moon illumination (Tab F-2). Aircraft preflight inspections found no major issues (Tab D-24). The ME had received a 200-hour borescope inspection two days prior to the mishap, with no abnormalities noted (Tab D-25). The MA flew one full-length ATO sortie the day prior to the mishap (Tab D-3). On the mishap sortie, the MP originally started another aircraft but, due to a problem with its navigational system, ground aborted that aircraft (Tab V-1.5). The MP then stepped to the MA: a dedicated spare that had received a proper preflight inspection (Tabs D-24 and V-1.7). Engine start, arming, and taxi of the MA occurred without issue (Tab V-1.7).

d. Summary of Accident – See Diagram 1 below.

During take-off roll, the MA had good thrust and the MP found the ME to be working properly with all engine instruments indicating normal readings (Tab V-1.5). The MA accelerated at a normal rate, and the MP rotated the aircraft approximately 17.5 seconds after selecting maximum power (max afterburner (AB)) (Tab J-8). The MA lifted off four seconds later, and the MP retracted the landing gear 2.5 seconds thereafter (Tab J-8). Approximately 1.7 seconds after the MP moved the landing gear handle to the up position, while the landing gear was still in transit, the MP saw a giant explosion with white sparks shooting out the front of the MA, heard some loud grinding and two big thumps, and felt significant vibrations (Tabs J-8 to J-9, V-1.15, and V-3.1). At that point, the MA was 20' Above Ground Level (AGL) at 200 Knots Calibrated Airspeed (KCAS) and the MP initiated a climb maneuver (Tab J-9). The climb resulted in an altitude of 880' AGL with the airspeed decreasing below 170 KCAS (Tab J-9). Twenty-six seconds after the initial malfunction, the MP initiated the ejection sequence (Tab J-9). The throttle was in max AB; however, the ME was operating at a significantly degraded thrust level and impacted the ground less than eight seconds later at a nearly wings-level attitude (Tab J-5).

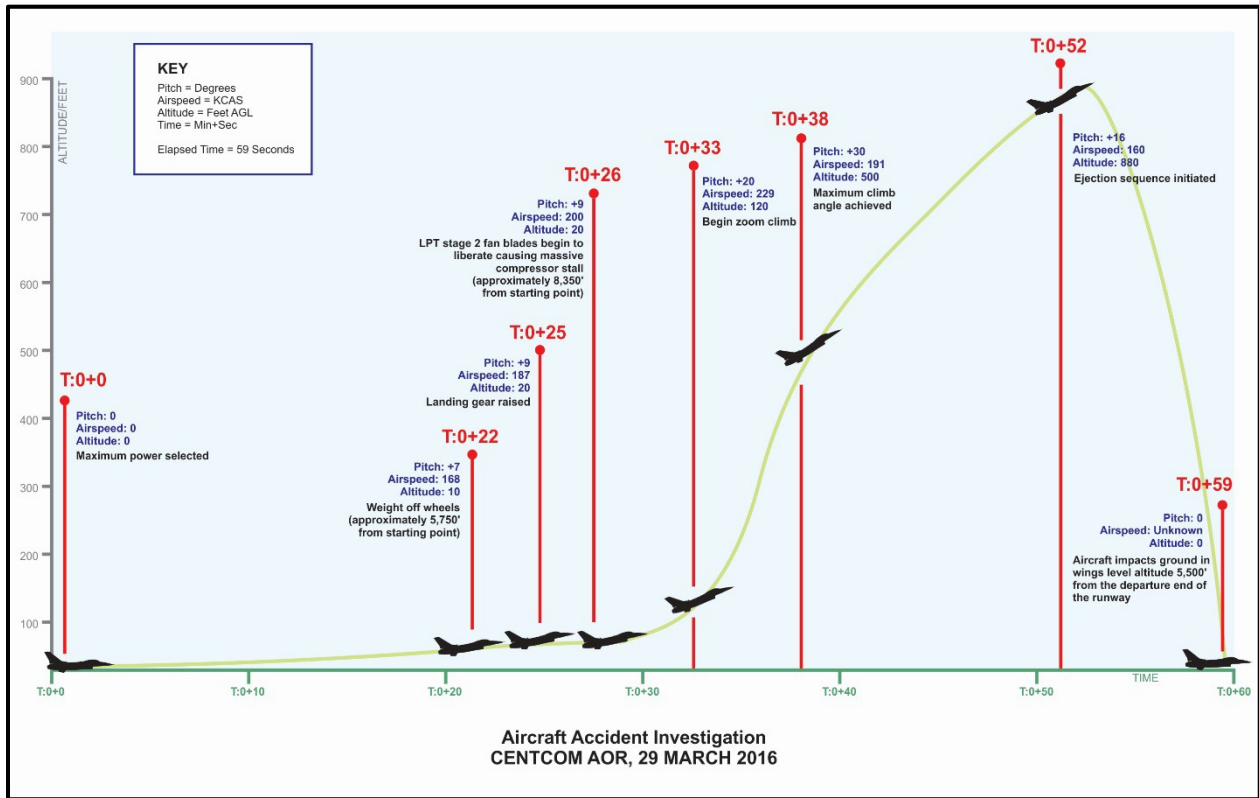


Diagram 1. CENTCOM F-16 Mishap Flight Path (Tab Z-2)

Immediately after takeoff and with the landing gear in transit, at least one blade of the Stage 2 Low Pressure Turbine (LPT) Rotor Assembly liberated and went on to damage all 94 blades of the Stage 2 LPT (Tabs J-36, S-38 to S-40, and V-1.5). This damage resulted in an imbalance within the ME that created significant vibrations and loud grinding noises audible to the MP (Tab V-1.5).

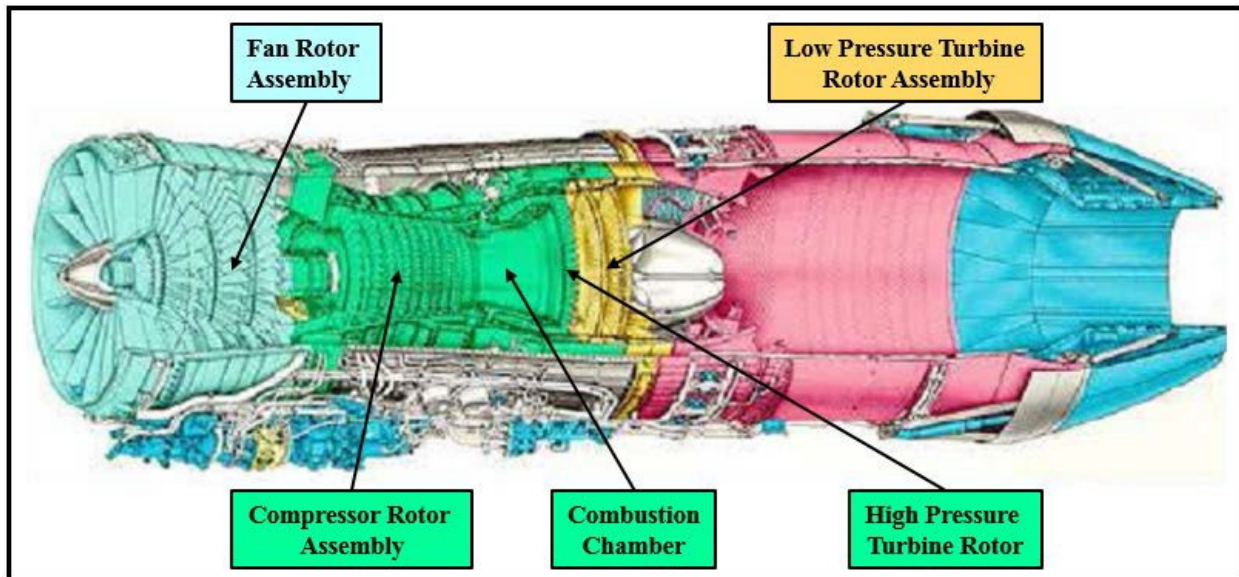


Figure 5. F110-100C Engine Cross-Section Overview (Tab Z-3)

e. Impact

At 2027L—37 seconds after takeoff—the MA impacted the ground approximately 5,500’ from the departure end of the runway (Tab J-5 and N-2). The MA wreckage was scattered across a 660’ debris field in an unpopulated agricultural area (Tab J-5). At the time of impact, the configuration of the MA was a combat loadout with external fuel tanks still nearly full (Tab J-5). The aircraft impacted the ground; and the throttle was recorded in the max AB position, but with the ME reading 61% fan Revolutions per Minute (RPM) and 85.5% core RPM (Tab J-9). Upon impact, the MA broke apart leaving the ME intact, separated from the rest of the aircraft, but with significant damage (Tab J-22). The recovered aircraft wreckage was transferred to Hill AFB for evaluation. (Tab H-5)

f. Egress and Aircrew Flight Equipment (AFE)

Fifty-two seconds from brake release, the MA airspeed had decreased to below 170 KCAS and had reached the maximum achievable altitude of 880’ AGL (Tab J-8 to J-9). At which point the MP initiated the ejection sequence (Tab V-1.5). Ejection was successfully accomplished within the component limitations of the egress system. (Tab H-8) Post-accident analysis of the life support equipment and records revealed the inspections were up-to-date and that the equipment functioned properly (Tab H-49 to H-50). With the exception of the inertial reel, the egress system functioned properly (Tab H-6 to H-8). During an ejection, the inertial reel should retract fully, holding the pilot firmly against the backrest of the seat (Tab H-6). Here, the evidence showed the inertial reel traveled only .68” of the possible 1.6” available (Tab H-6). The inertial reel was provided to the Life Sciences Equipment Laboratory for further analysis (Tab H-8). During the ejection sequence, the MP sustained only minor injuries, (Tab V-1.6).

g. Combat Search and Rescue (CSAR)

Immediately after the MP ejected at 2027L, the MW began coordinating the CSAR effort by contacting two attack helicopters that were in the tower pattern, directing them to the crash site to search for the MP (Tab V-2.3). Also, the MW directed squadron operations to scramble the CSAR helicopter forces (Tab V-2.3). Furthermore, realizing a group of Joint Attack Controllers were performing patrols in the area, the MW established contact with the ground forces and directed them to the crash site (Tabs R-26, R-27, and V-2.3). Given the close proximity of the crash site to the air base, the MP ran from the landing site to the nearest air base Entry Control Point (ECP) (Tab V-1.6), arriving 10-15 minutes after ejection (Tab R-60). Upon the MP's arrival at the ECP, guards contacted the rescue forces and the helicopters landed, picked up, and transported the MP to the base hospital for medical evaluation (Tab V-1.6).

h. Recovery of Remains

Not applicable.

5. MAINTENANCE

a. Forms Documentation

Air Force Technical Order (AFTO) 781-series forms document all discrepancies and maintenance actions performed on the MA (Tab D-2 to D-52). Historical records and Integrated Maintenance Data System (IMDS) maintenance documentation were properly entered and complete (Tabs D-2 to D-52 and U-2). Prior to the mishap, the MA accumulated 7,293.3 flight hours (Tab D-5).

Time Compliance Technical Orders (TCTOs) are inspections or maintenance procedures requiring completion by specific dates, flight hours, or engine operating hours (Tabs D-9, D-11, and U-2). No TCTOs restricted the MA from flying (Tabs D-9, D-11, and U-2). Historical records showed the TCTOs were accomplished IAW applicable guidance (Tabs D-9, D-11, and U-2).

In 2010, the ME, an F110-GE-100-C, serial number GEOE509110C, was last overhauled (Tab D-2). From 2011 to 2012, the ME was installed in aircraft T/N 88-0415 with no defects noted (Tab D-34). On 06 February 2013, the ME was installed in the MA where it remained until the mishap (Tab D-2). A review of historical records did not reveal any recurring maintenance problems (Tab D-34 and D-35).

b. Inspections

In December 2015, maintenance personnel performed a 400-hour airworthiness inspection on the MA with no discrepancies noted (Tab D-2).

Beginning at 1900L on 26 March 2016 and ending at 0900L on 27 March 2016, a scheduled 200-hour Engine Borescope inspection was accomplished IAW applicable TOs (Tab D-25 to D-32). At the time, the ME had 2,618.1 engine operation hours, which, due to aircraft availability, underwent its 200-hour borescope inspection 28.9 hours ahead of schedule (Tab D-5 and D-7). The MA was not scheduled to fly for the duration of the inspection and all follow-on and

operational checks and maintenance documentation were accomplished without defect (Tab D-2 and D-25 to D-32).

On 28 March 2016, at 1200L, the MA underwent a Basic Post-flight/Pre-flight (BPO/PR) which was valid for three days (Tabs U-2 and V-5.2). No defects were noted (Tab D-20). At the time of the MA sortie, the BPO/PR was current (Tab D-20).

c. Maintenance Procedures

A review of MA's AFTO 781-series forms and IMDS database revealed maintenance actions complied with standard approved maintenance procedures and TOs (Tabs D-2 to D-50 and U-2).

d. Maintenance Personnel and Supervision

The personnel involved in maintaining the MA were qualified and proficient in their respective duties (Tab U-2). A review of the maintenance training records (AF Forms 623 and 797) revealed no training deficiencies (Tab U-2).

e. Fuel, Hydraulic, and Oil Inspection Analyses

Fuel, oil lubricants, and hydraulic samples from the fuel truck, service carts, and MA were analyzed and determined to meet material test requirements (Tab D-33). Additionally, a review of inspection records on the servicing carts used on the MA revealed no discrepancies (Tabs D-33 and U-2). As no post-accident fluid samples were taken, all fluid samples collected were preflight samples (Tabs D-33 and U-2).

f. Unscheduled Maintenance

Weapons Section personnel performed unscheduled maintenance on the MA on 27 March 2016 by removing all impulse carts from the MA in preparation of electrical functional checkout of a newly installed launcher to aircraft interface cable (Tab D-16). The system was checked with no defects noted (Tab D-16). All follow-on actions and operational checks were completed and properly documented (Tab D-16). Crew Chief personnel performed unscheduled maintenance on the MA on 28 March 2016 when they discovered the left main landing gear tire pressure was out of limits (Tab D-22). The tire was properly serviced and documented in the aircraft forms (Tab D-22).

6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS

a. Structures and Systems

The MA broke apart upon impact with debris spanning a field 660' across a 30° fan pattern. (Tab J-5). Lockheed Martin Aeronautics conducted a post-mishap analysis of the Crash Survivable Memory Unit (CSMU), the Digital Flight Control System (DFLCS) memory, and the Signal Acquisition Unit (SAU) (Tab J-7 to J-13). All aircraft systems (electrical, hydraulic, fuel and flight

controls) were determined to be operating properly at the time of the malfunction through impact (Tab J-12 to J-14).

(1) Crash Survivable Flight Data Recorder

Data recovered from the Crash Survivable Flight Data Recorder (CSFDR) showed that the MA engine core RPM rolled back immediately following a max AB takeoff and the CSFDR recorded Maintenance Fault List (MFLs) codes consistent with an engine compressor stall (Tab J-11).

(2) Engine Analysis

The liberation of a Stage 2 LPT blade resulted in significant Stage 2 LPT Assembly damage (Figures 1-3) (Tab S-38 to S-40). This led to an immediate rollback to the Fan Rotor Assembly RPM that eventually caused the ME to experience a compressor stall (Tab J-9 and J-10). A metallurgical investigation performed by General Electric (GE) showed all 94 Stage 2 LPT blades fractured due to “overstress” (Tab J-44). A scanning electron microscope examination of nine blades showed no evidence of “creep” (stretching) or “over-temperature” (Tab J-45). The GE metallurgical report showed no evidence of a pre-existing condition in the Stage 2 LPT (Tab J-44). The damage to the Stage 2 LPT Assembly was so drastic it created an imbalance within the engine components, which led to eccentric rotational damage to other major ME components (Tab J-33).



Figure 1. Stage 2 LPT Damage (Tab S-38)

Figure 2. Stage 2 LPT Damage (Tab S-39)



Figure 3. Stage 2 LPT Damage (Tab S-40)

Engineering analysis of the CSFDR indicates the engine experienced uncommanded RPM rollback, followed by an immediate rise in ME temperatures, and a near simultaneous compressor stall of the ME fan and core sections (Tab J-9 and J-11). The ME RPMs never again exceeded 61% (Fan RPM) and 85.5% (Core RPM), respectively (Figure 4) (Tab J-9 and J-41). Data gathered from the CSFDR also revealed the ME continued to operate at a low power condition until ground impact (Tab J-42).

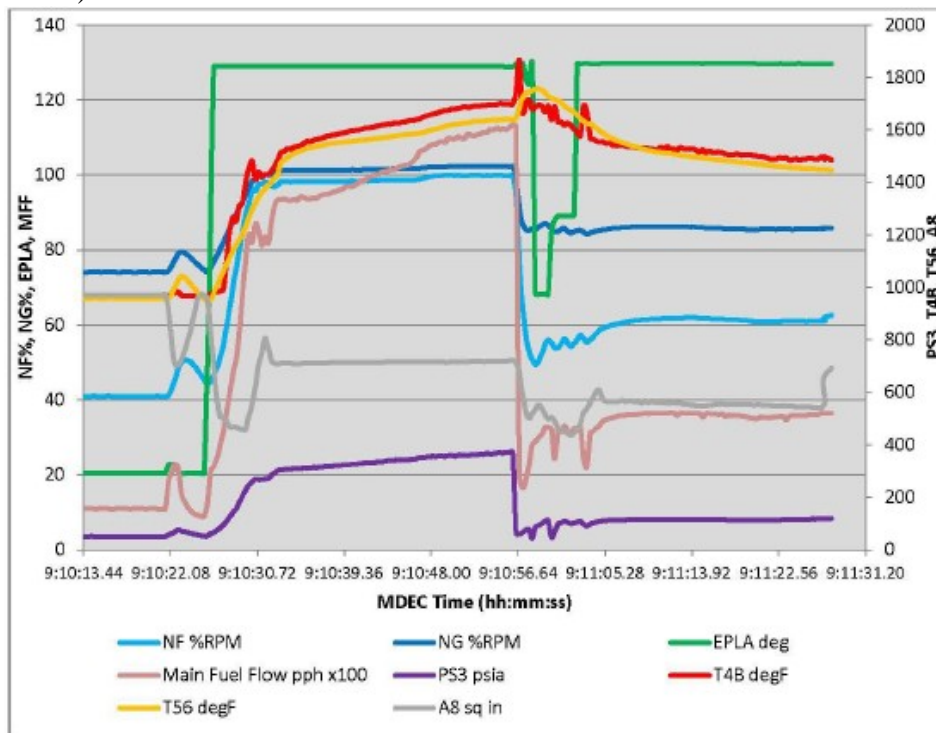


Figure 4. MDEC Recorded Engine Parameters (Tab J-41)

b. Evaluation and Analysis

The AIB collected three analyses (Tab J) and five evaluations from subject matter experts (SMEs) (Tab DD-2 to DD-10). While blade failure/liberation was cited by the SMEs below, there was no consensus or insufficient data regarding the pre-existing condition of the relevant blade(s). (Tab DD-2 to DD-10).

(1) Analysis 1

Lockheed Martin (LM) conducted an analysis of the MA Crash CSFDR and provided a detailed report of the major aircraft systems (Tab J-2 to J-16). The LM report concluded all aircraft systems (electrical, hydraulic, fuel and flight controls) were operating properly throughout the flight until ground impact (Tab J-12 to J-14). Further analysis of the CSFDR data indicated that the ME core RPM rolled back immediately after takeoff, while in full AB, with associated engine stall MFLs (Tab J-11).

(2) Analysis 2

Tinker Engineering (TE) assisted in the teardown and inspection of the ME at Hill AFB (Tab J-23). The ME was recovered from the crash site mostly intact with evidence of significant damage consistent with low-speed shallow-angle ground impact (Tab J-24). The three main engine component sections (Fan, High Pressure Compressor, and Low Pressure Compressor) exhibited damage patterns to suggest that the engine was operating in a significantly degraded state at the time of impact (Tab J-42 and Tab S-36 to S-40). TE also discovered damage in the Low and High Pressure Compressor sections that occurred while the engine was operating prior to ground impact (Tab J-31 to J-33). TE specifically identified extensive wear damage to the High Pressure Turbine blades caused by eccentric rotation (Tab J-31) and damaged blades in the Stage 2 LPT consistent with blade liberation while the MA was still airborne (Tab J-33).

(3) Analysis 3

The GE analysis concluded that all 94 Stage 2 LPT blades were fractured with features consistent with overstress (Tab J-44). Further analysis indicated that there was no evidence of creep or over-temperature and the blade structures and composition were consistent with proper material standards (Tab J-44). For further details, see paragraph 6.a(2).

(4) Evaluation 1

Upon reviewing the available relevant data from the mishap wreckage, a lead aerospace engineer (SME 1) assessed that upon Stage 2 LPT blade liberation, the ME experienced an uncontrolled rollback in engine speed; meaning the engine speeds from that point forward did not correspond to the engine scheduled speeds commensurate with CSFDR recorded throttle settings (Tab DD-4). The Digital Engine Control's inability to manage engine speed via fuel flow caused a transfer to HYBRID Mode, whereupon the Main Engine Control attempted to regulate engine speed mechanically but to no avail (Tab DD-4). SME 1 determined that there was a failure of a single Stage 2 LPT blade that went on to bring about overload failures of the remaining 93 blades of the Stage 2 Fan Assembly (Tab DD-6). This resulted in a significant loss of proper LPT functionality, thereby creating a loss of compression, which led to the engine stall (Tab DD-2 to DD-7).

(5) Evaluation 2

A second aerospace engineer (SME 2) thoroughly reviewed relevant data from the mishap wreckage and assessed that there existed signs of abnormal ME operation post Stage 2 LPT blade failure that likely occurred prior to ground impact (Tab DD-8). Those signs were indications of secondary damage in other ME components that occurred because of the imbalance the Stage 2 LPT degeneration caused (Tab DD-8). The Stage 2 LPT blade failure was the catalyst behind a 'wobbling' effect leading to abnormal rubbing of other turbine assemblies throughout the ME (Tab DD-8). Furthermore, the compressor stall that followed the LPT breakdown placed the ME in a condition where normal engine performance was unable to recover (Tab DD-8).

(6) Evaluation 3

An F110-GE-110 engine overhaul expert (SME 3), after thoroughly analyzing physical wreckage, photographic documentation of the wreckage site, and relevant flight data recorder material, deduced that the trigger event that led to the ME malfunction was when one or more Stage 2 LPT fan blades failed, severely degrading the overall airflow capacity thereafter (Tab DD-9). SME 3 also attested to the fact that current Air Force inspection procedures require detailed inspections on various engine components, and the training, tooling, and procedural guidance to conduct such inspections are in place specifically to discover surface defects that may lead to failures of this type (Tab DD-9). Furthermore, SME 3 opined that had any obvious damage or surface defects been present at the time of the last borescope inspection, maintenance personnel would have been able to discover it (Tab DD-9).

(7) Evaluation 4

A structural materials evaluation team lead (SME 4) concluded the physical evidence of mishap wreckage is consistent with a pre-existing flaw in one of the LPT blades, leading to blade liberation and failure before ground impact (Tab DD-10). Unfortunately, damage to the engine components prevented a conclusive determination of the nature of any preexisting flaws (Tab DD-10).

(8) Evaluation 5

The AIB Pilot Member conducted multiple F-16CM Unit Training Device simulator trials under similar atmospheric conditions and degraded engine performance that were present at the time of the mishap and revealed it was extremely unlikely the MA had sufficient thrust to maintain level flight or execute a climb to an altitude where a safe landing could occur (Tab EE-2 to EE-3).

7. WEATHER

a. Forecast Weather

The USCENTCOM AOR Weather Flight provided the mission execution forecast for 29 March 2016 (Tab F-6). The forecast included winds variable at six knots, clouds broken at 15,000' mean sea level, temperature six degrees Celsius, and unrestricted visibility (Tab F-6).

b. Observed Weather

The observed weather at the airfield were winds out of the northwest at nine knots, partly cloudy skies, temperature six degrees Celsius, altimeter 30.11 pounds per square inch, and unrestricted visibility (Tab F-6 to F-7).

c. Space Environment

Not applicable.

d. Operations

There is no evidence to suggest that MA was operating outside its prescribed operational weather limitations.

8. CREW QUALIFICATIONS

a. Mishap Pilot

The MP was a current and qualified 4-ship flight lead and Forward Air Controller-Airborne in the F-16CM (Tab G-2). The MP’s last mission evaluation was successfully completed on 5 October 2015 (Tab G-35). The MP completed an instrument evaluation on 19 December 2014 and was due for another evaluation in May of 2016 (Tab G-35 and G-40). At the time of the mishap, the MP had accrued a total of 943.2 flight hours with 708 hours in the F-16 and 220.1 combat hours (Tab G-3 and G-4).

The MP’s recent flight time up to the mishap was as follows (Tab G-6):

	Hours	Sorties
Last 30 Days	44.7	12
Last 60 Days	102.4	29
Last 90 Days	154.3	42

9. MEDICAL

a. Qualifications

The MP was medically qualified for flight duties without restriction at the time of the mishap (Tab X-2). On 28 September 2015, the MP received a medical clearance and was deemed “medically cleared” via Department of Defense (DoD) Form 2992 as part of an annual flight physical, with an expiration of 25 December 2016 (Tab X-2). A review of MP’s medical records revealed the MP had no medical waivers (Tab X-4).

b. Health

A review of medical records, as well as post mishap physical exam, revealed the MP was in good physical health and had no recent performance-limiting illnesses prior to the mishap (Tab X-4). The MP had a current physical health assessment as mentioned above (Tab X-2). Further, the MP sustained only minor injuries as result of the mishap following the ejection (Tab X-4).

c. Pathology

The Armed Forces Medical Examiner System tested blood and urine samples in accordance with AFI 91-204, *Safety Investigations and Reports* (Tab BB-3). These tests identify carbon monoxide and ethanol levels in the blood and detect traces of drugs (amphetamine, barbiturates, benzodiazepines, cannabinoids, cocaine, opioids, phencyclidine, and sympathomimetic amines) in urine (Tab X-4). The following members were tested: MP, MW, EBS1, DDC4, MA maintenance crewmembers, and all mishap Air Traffic Control (ATC) members (Tab X-4). All results were negative (Tab X-4).

d. Lifestyle

There is no evidence to suggest that MP, MW, Maintenance Members, or ATC members' lifestyle were a factor in this mishap (Tab X-4).

e. Crew Rest and Crew Duty Time

IAW AFI 11-202, Volume 3, *General Flight Rules*, aircrew members are required to receive a minimum of 12 non-duty hours of crew rest prior to performing flight duty (Tab BB-4 to BB-5). During this time, a crewmember may participate in meals, transportation, or rest (Tab BB-4 to BB-5). This time must include an opportunity for at least 8 hours of uninterrupted sleep (Tab BB-4 to BB-5). Crew rest period cannot begin until after the completion of official duties (Tab BB-4 to BB-5). Although the 72-hour and 14-day history records for MP were unavailable for review in writing (Tab R-11), the MP stated, during the interview, adequate crew rest was available (Tab V-1.4).

10. OPERATIONS AND SUPERVISION

a. Operations

In October 2015, the 421 FS deployed to the USCENTCOM AOR in support of OPERATION FREEDOM'S SENTINEL and RESOLUTE SUPPORT (Tab V-2.12 and V-3.2). The squadron re-deployed to home station in May 2016 (Tab V-2.12). The MP arrived in theater in November 2015 and re-deployed to home station on 16 April 2016 for a subsequent permanent change of station (Tab V-1.3). The MP stated that the operations tempo was a little higher than at home station (Hill AFB, UT) but still had time to relax (Tab V-1.4). The unit pilots were allowed a couple of days to adjust to new shift schedules prior to flying and were given a day off every two weeks (Tab V-1.4).

b. Supervision

Prior to the mishap sortie, the 421 FS Operations Supervisor confirmed the MP had read all applicable Read Files, Special Instructions, Flight Crew Information Files and had conducted an Operational Risk Management assessment for the tasked sortie (Tab T-2). Prior to the sortie, the MP's currency on Critical Action Procedures (CAPs), Simulated Emergency Procedures Training and Aircrew Flight Equipment Fit Check were also verified (Tab G-27).

11. HUMAN FACTORS ANALYSIS

The AIB considered all human factors as prescribed in the Department of Defense Human Factors Analysis and Classification System 7.0 (DoD HFACS 7.0) (Tab BB-9 to BB-14). There is no evidence to suggest human factors contributed to the mishap.

12. GOVERNING DIRECTIVES AND PUBLICATIONS

a. Publicly Available Directives and Publications Relevant to Mishap

- (1) AFI 51-503, *Aerospace and Ground Accident Investigations*, 14 April 2015
- (2) AFI 91-204, *Safety Investigations and Reports*, 12 February 2014, Corrective Actions Applied on 10 April 2015
- (3) AFI 11-202, Volume 3, *General Flight Rules*, 7 November 2014

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

b. Other Directives and Publications Relevant to the Mishap

- (1) DOD HFACS Version 7.0
- (2) TO 1F-16CM-1, *Flight Manual USAF Series F-16C and F-16D*, 1 October 2015

c. Known or Suspected Deviations from Directives or Publications

None.

//Signed//

28 JUNE 2016

THOMAS N. JOHNSON, Colonel, USAF
President, Accident Investigation Board

STATEMENT OF OPINION

**F-16CM, T/N 88-0518
USCENTCOM AOR
29 MARCH 2016**

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

1. OPINION SUMMARY

On 29 March 2016, at 2027 local time, in the United States Central Command (USCENTCOM) Area of Responsibility (AOR), the Mishap Aircraft (MA), an F-16CM, tail number 88-0518, assigned to the 421st Fighter Squadron, 388th Fighter Wing, Hill Air Force Base, Utah, suffered a hardware malfunction in the Mishap Engine (ME), resulting in an uncommanded engine rollback shortly after takeoff which triggered an unrecoverable compressor stall. The Mishap Pilot (MP) immediately executed a climb maneuver, ejected safely, and only sustained minor injuries. The MA, valued at \$25,335,314, was destroyed. Including other government property, the total government loss for this mishap is valued at \$29,076,216. In addition, there was some damage to non-government land and crops.

The MP was the lead of a night two-ship formation flying an alert scramble Air Tasking Order (ATO) sortie in the USCENTCOM AOR. The MP and Mishap Wingman (MW) stepped to aircraft that had previously received proper preflight inspections. During ground operations of the primary aircraft, the MP identified a navigation system error that caused MP to step to a spare aircraft. After transitioning to the MA, the MP started the engine, armed, and taxied uneventfully. After receiving priority takeoff clearance, the MP initiated a maximum afterburner (AB) takeoff. During takeoff roll, the MP verified that the MA had good thrust via engine instruments and rotated the aircraft for takeoff with no issues. Shortly after the aircraft lifted off the ground (2-3 seconds), with two indications of a positive climb rate, the MP raised the landing gear handle. While still in full AB and with the landing gear still in transition, the MP simultaneously saw a giant explosion with white sparks shoot out the front of the MA, heard some loud grinding and two big thumps, and felt significant vibration throughout the airframe. At that point, the MA was approximately 20' Above Ground Level (AGL) at 200 Knots Calibrated Airspeed (KCAS). The MP, recognizing the degraded ME thrust, initiated a climb maneuver, resulting in a maximum altitude of 880' AGL with the airspeed decreasing below 170 KCAS. At that point, the MP initiated the ejection sequence. At the time of the ejection, the MA was in full AB but operating in a significantly reduced thrust condition. After ejection, the MP observed the aircraft descend rapidly and impact the ground less than eight seconds later at a nearly wings-level attitude.

Post-flight analysis of flight data recorders and wreckage revealed the following information that explains the reduced ME performance; please see Figure 5. Immediately after takeoff and with

the landing gear in transit, at least one blade of the Stage 2 Low Pressure Turbine (LPT) Rotor Assembly liberated, which went on to damage all 94 blades of the Stage 2 LPT. This damage resulted in an imbalance within the ME that created significant vibrations and loud grinding noises audible to the MP.

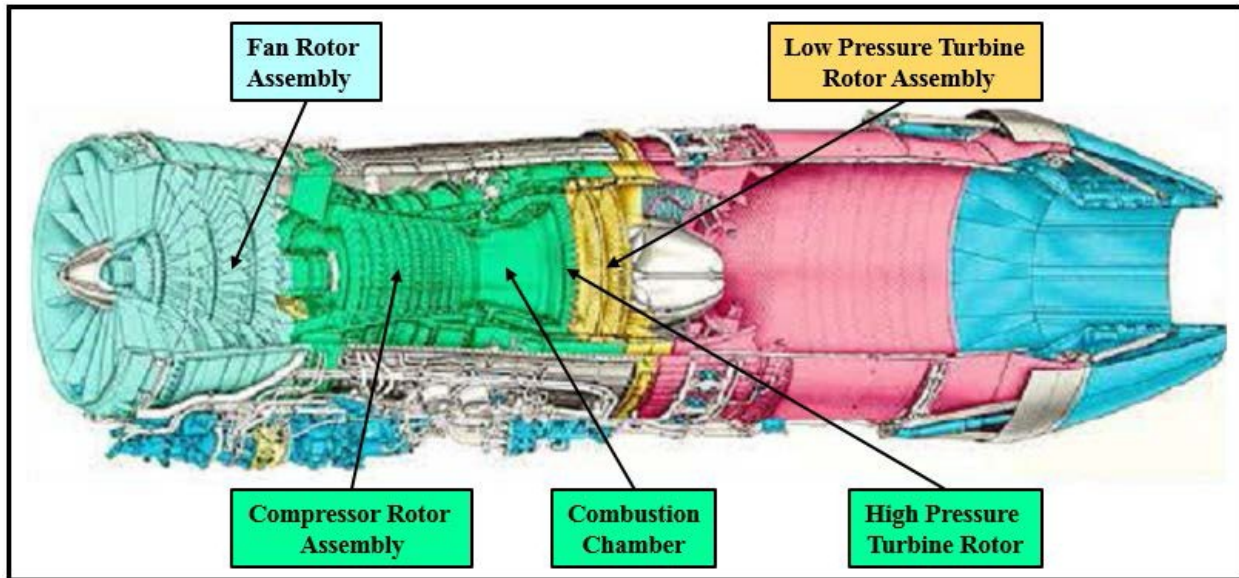


Figure 5. F110-100C Engine Cross-Section Overview

The immediate effect of the LPT damage was an interruption in airflow that caused a compressor stall, as evidenced by numerous loud thumps and engine rollback. The more lasting effect of the LPT damage was a resulting drop in the Fan Rotor Assembly Revolutions per Minute (RPM) that hindered the Compressor Rotor Assembly from providing the necessary airflow to the Combustion Chamber to create adequate thrust. Identifying that there existed significant mechanical problems, the MA's Digital Electronic Control (DEC) transitioned the ME to a Hybrid mode of operation, which is where fuel flow scheduling and metering was controlled by the Main Engine Control (MEC) system. The MP predominately left the MA's throttle in the max AB position, except for a short cycling of the throttle to attempt to clear the stall. The extent of the damage caused the MEC to operate the Front Rotor Assembly at 61% RPM and limited the Core Rotor Assembly at 85.5% RPM. The ultimate result was insufficient thrust to maintain adequate airspeed or altitude for continued safe flight, and left the MP with only one reasonable decision—to eject.

I find, by a preponderance of the evidence, the cause of the mishap to be material failure of at least one Stage 2 Low Pressure Turbine blade, which induced an unrecoverable compressor stall shortly after takeoff. This event rendered the ME incapable of providing necessary thrust to maintain continued flight.

I developed my opinion by analyzing factual data from witness testimony and information provided by subject matter experts to include technical reviews, engineering and laboratory testing, flight simulator trials, and analysis of post-mishap aircraft components.

2. CAUSE

The cause of the mishap was material failure of at least one Stage 2 Low Pressure Turbine blade, which induced an unrecoverable compressor stall shortly after takeoff. This event rendered the ME incapable of providing necessary thrust to maintain continued flight.

The liberation (breaking loose) of a Stage 2 LPT fan blade caused a ripple effect that left the LPT Rotor Assembly severely damaged. The liberation and wearing down of all other Stage 2 LPT blades not only significantly limited its ability to drive the Fan Rotor Assembly (thereby inhibiting airflow necessary for proper ME functionality), it also induced vibration that detrimentally effected the Compressor Rotor Assembly's performance. As both Assemblies are critical to supplying air to the Combustion Chamber, their combined degradation partially suffocated the ME and yielded far less than ordinary thrust. If not for the Stage 2 LPT disintegration, the mishap would not have occurred.

3. CONCLUSION

I find, by a preponderance of the evidence, the cause of the mishap to be material failure of a Stage 2 Low Pressure Turbine blade, which induced an unrecoverable compressor stall shortly after takeoff. This event rendered the ME incapable of providing necessary thrust to maintain continued flight.

//Signed//

28 JUNE 2016

THOMAS N. JOHNSON, Colonel, USAF
President, Accident Investigation Board

INDEX OF TABS

Safety Investigator Information	A
Not used	B
Not used	C
Maintenance Report, Records, and Data.....	D
Not used	E
Weather And Environmental Records and Data.....	F
Personnel Records.....	G
Egress, Aircrew Flight Equipment, Impact, and Crashworthy Analysis	H
Deficiency Reports.....	I
Releasable Technical Reports and Engineering Evaluations.....	J
Mission Records and Data	K
Factual Parametric, Audio, and Video Data From On-Board Recorders	L
Data From Ground Radar And Other Sources	M
Transcripts Of Voice Communications	N
Any Additional Substantiating Data and Reports	O
Damage Summaries	P
AIB Transfer Documents.....	Q
Releasable Witness Testimony	R
Releasable Photographs, Videos, Diagrams, and Animations.....	S
Personnel Flight Records Not Included In Tab G.....	T
Maintenance Report, Records, And Data Not Included In Tab D	U
Witness Testimony And Statements	V

Weather And Environmental Records, and Data Not Included In Tab F W
Statements of Injury or Death X
Legal Board Appointment Documents Y
Photographs, Videos, Diagrams, and Animations Not Included In Tab S Z
Flight Documents..... AA
Applicable Regulations, Directives, and Other Government Documents BB
Fact Sheets CC
Subject Matter Expert Analyses..... DD
F-16 Simulator Reenactment Results..... EE