07/19/89 United Airlines

Official Accident Report Index Page

Report Number	NTSB/AAR-90/06
Access Number	PB90-910406
Report Title	United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux Gateway Airport, Sioux City, lowa, July 19, 1989
Report Date	November 1, 1990
Organization Name	National Transportation Safety Board Office of Aviation Safety Washington, D.C. 20594
WUN	5158D
Sponsor Name	NATIONAL TRANSPORTATION SAFETY BOARD Washington, D.C. 20594
Report Type	Aircraft Accident Report July 19, 1989
Distribution Status	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161
Report Class	UNCLASSIFIED
Pg Class	UNCLASSIFIED
Pages	126
Abstract	This report explains the crash of a United Airlines McDonnell Douglas DC-10-10 in Sioux City, Iowa, on July 19, 1989. The safety issues discussed in the report are engine fan rotor assembly design, certification, manufacturing, and inspection; maintenance and inspection of engine fan rotor assemblies; hydraulic flight control system design, certification, and protection from uncontained engine debris; cabin safety, including infant restraint systems; and aircraft rescue and firefighting facilities. Safety recommendations addressing these issues were made to the Federal Aviation Administration and the U.S. Air Force.

Facts of the Accident

Accident NTSB ID	90-06
Airline	United Airlines
Model aircraft	DC-10-10, N1819U
Year shipped	1971
Aircraft manufacturer	McDonnell Douglas
Engine type	CF6-6
Engine manuafacturer	General Electric Aircraft Engines
Date	07/19/89
Time	1549
Location	Sioux Gateway Airport, Sioux City, Iowa
Country	USA
Fatalities	111
Injuries	172
Fire during flight?	N
Fire on the ground?	Y
Probable cause	Inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility which resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines. The separation, fragmentation, and forceful discharge of uncontained stage 1 fan rotor assembly parts from the No. 2 engine led to the loss of the three hydraulic systems that powered the airplane's flight controls.
Weather conditions	15 miles visibility
Total crew size	11
Cockpit crew size	3
Cabin crew size	8
Passengers	285
Report ID	NTSB/AAR-90/06
Pages	126
Day or night?	Day
Flight number	232
Flight origin	Denver, CO
Flight destination	Philadelphia, PA
Description	This flight experienced a catastrophic failure of the No. 2

tail-mounted engine during cruise flight. The separation, fragmentation and forceful discharge of stage 1 fan rotor assembly parts from the No. 2 engine led to the loss of the three hydraulic systems that powered the airplane's flight controls. The flightcrew experienced severe difficulties controlling the airplane, which subsequently crashed during an attempted landing at Sioux Gateway Airport, Iowa.

Executive Summary

On July 19, 1989, at 1516, a DC-10-10, N1819U, operated by United Airlines as flight 232, experienced a catastrophic failure of the No. 2 tail-mounted engine during cruise flight. The separation, fragmentation and forceful discharge of stage 1 fan rotor assembly parts from the No. 2 engine led to the loss of the three hydraulic systems that powered the airplane's flight controls. The flightcrew experienced severe difficulties controlling the airplane, which subsequently crashed during an attempted landing at Sioux Gateway Airport, Iowa. There were 285 passengers and 11 crewmembers onboard. One flight attendant and 110 passengers were fatally injured.

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility which resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines. The subsequent catastrophic disintegration of the disk resulted in the liberation of debris in a pattern of distribution and with energy levels that exceeded the level of protection provided by design features of the hydraulic systems that operate the DC-10's flight controls.

The safety issues raised in this report include:

1. General Electric Aircraft Engines' (GEAE) CF6-6 fan rotor assembly design, certification, manufacturing, and inspection.

2. United Airlines' maintenance and inspection of CF6-6 engine fan rotor assemblies.

3. DC-10 hydraulic flight control system design, certification and protection from uncontained engine debris.

4. Cabin safety, including infant restraint systems, and airport rescue and firefighting facilities.

Recommendations concerning these issues were addressed to the Federal Aviation Administration, the Secretary of the Air Force, the Air Transport Association and the Aerospace Industries Association.

1. Factual Information

1.1 History of Flight

United Airlines (UAL) flight 232 (UA 232), a McDonnell Douglas DC-10-10, registration No. N1819U, was a scheduled passenger flight from Stapleton International Airport, Denver, Colorado, to Philadelphia, Pennsylvania, with an en route stop at Chicago, Illinois. The flight was conducted under Title 14 Code of Federal Regulations (CFR) Part 121. Flight 232 departed Denver at 1409 central daylight time. There were 285 passengers and 11 crewmembers on board.

The takeoff and the en route climb to the planned cruising altitude of 37,000 feet were uneventful. The first officer (copilot) was the flying pilot. The autopilot was engaged, and the autothrottles were selected in the speed mode for 270 KIAS. The flight plan called for a cruise speed of Mach 0.83.

About 1 hour and 7 minutes after takeoff, at 1516:10, the flightcrew heard a loud bang or an explosion, followed by vibration and a shuddering of the airframe. After checking the engine instruments, the flightcrew determined that the No. 2 aft (tail-mounted) engine had failed.(See figure 1). The captain called for the engine shutdown checklist. While performing the engine shutdown checklist, the second officer (flight engineer) observed that the airplane's normal systems hydraulic pressure and quantity gauges indicated zero.

The first officer advised that he could not control the airplane as it entered a right descending turn. The captain took control of the airplane and confirmed that it did not respond to flight control inputs. The captain reduced thrust on the No. 1 engine, and the airplane began to roll to a wings-level attitude.

The flightcrew deployed the air driven generator (ADG), which powers the No. 1 auxiliary hydraulic pump, and the hydraulic pump was selected "on." This action did not restore hydraulic power.

At 1520, the flightcrew radioed the Minneapolis Air Route Traffic Control Center (ARTCC) and requested emergency assistance and vectors to the nearest airport. Initially, Des Moines International Airport was suggested by ARTCC. At 1522, the air traffic controller informed the flightcrew that they were proceeding in the direction of Sioux City; the controller asked the flightcrew if they would prefer to go to Sioux City. The flightcrew responded, "affirmative." They were then given vectors to the Sioux Gateway Airport (SUX) at Sioux City, Iowa.(See figure 2). Details of relevant air traffic control (ATC) communications, cockpit conversations, airplane maneuvers, and airplane and engine system parameters are contained in Sections 1.9 and 1.11 of this report.

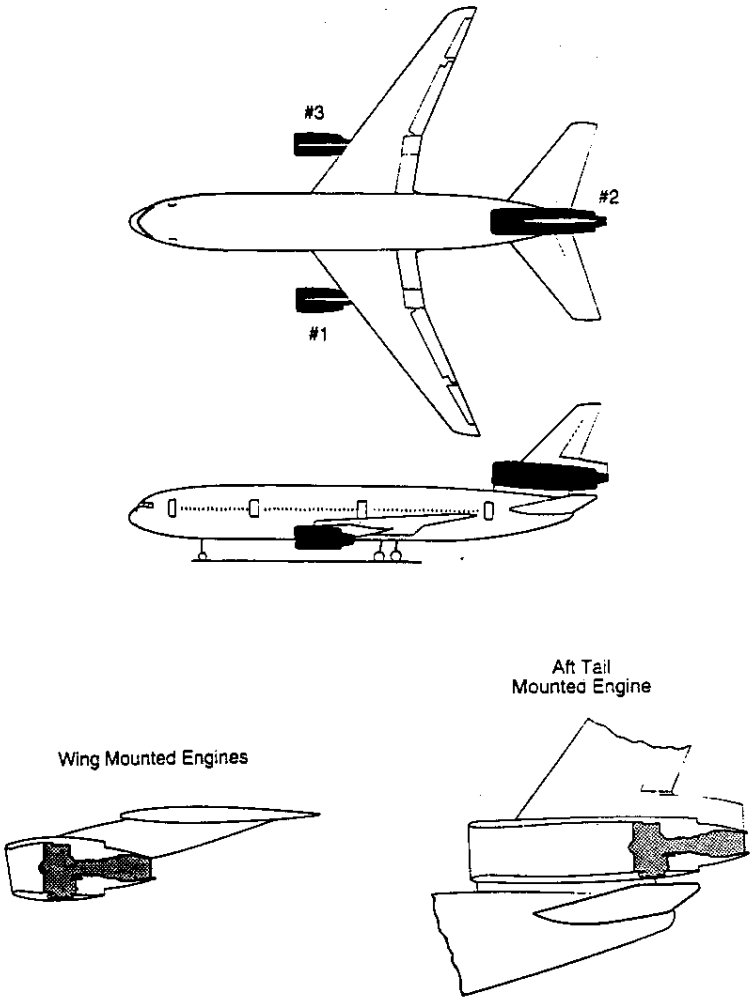

Figure 1.--DC-10 airplane view illustrated with engine arrangement.

Crew interviews indicate that shortly after the engine failure, the passengers were informed of the failure of the No. 2 engine, and the senior flight attendant was called to the cockpit. She was told to prepare the cabin for an emergency landing. She returned to the cabin and separately informed the other flight attendants to prepare for an emergency landing. A flight attendant advised the captain that a UAL DC-10 training check airman, who was off duty and seated in a first class passenger seat, had volunteered his assistance. The captain immediately invited the airman to the cockpit, and he arrived about 1529.

At the request of the captain, the check airman entered the passenger cabin and performed a visual inspection of the airplane's wings. Upon his return, he reported that the inboard ailerons were slightly up, not damaged, and that the spoilers were locked down. There was no movement of the primary flight control surfaces. The captain then directed the check airman to take control of the throttles to free the captain and first officer to manipulate the flight controls.

The check airman attempted to use engine power to control pitch and roll. He said that the airplane had a continuous tendency to turn right, making it difficult to maintain a stable pitch attitude. He also advised that the No. 1 and No. 3 engine thrust levers could not be used symmetrically, so he used two hands to manipulate the two throttles.

About 1542, the second officer was sent to the passenger cabin to inspect the empennage visually. Upon his return, he reported that he observed damage to the right and left horizontal stabilizers.

Fuel was jettisoned to the level of the automatic system cutoff, leaving 33,500 pounds. About 11 minutes before landing, the landing gear was extended by means of the alternate gear extension procedure.

The flightcrew said that they made visual contact with the airport about 9 miles out. ATC had intended for flight 232 to attempt to land on runway 31, which was 8,999 feet long. However, ATC advised that the airplane was on approach to runway 22, which was closed, and that the length of this runway was 6,600 feet. Given the airplane's position and the difficulty in making left turns, the captain elected to continue the approach to runway 22 rather than to attempt maneuvering to runway 31. The check airman said that he believed the airplane was lined up and on a normal glidepath to the field. The flaps and slats remained retracted.

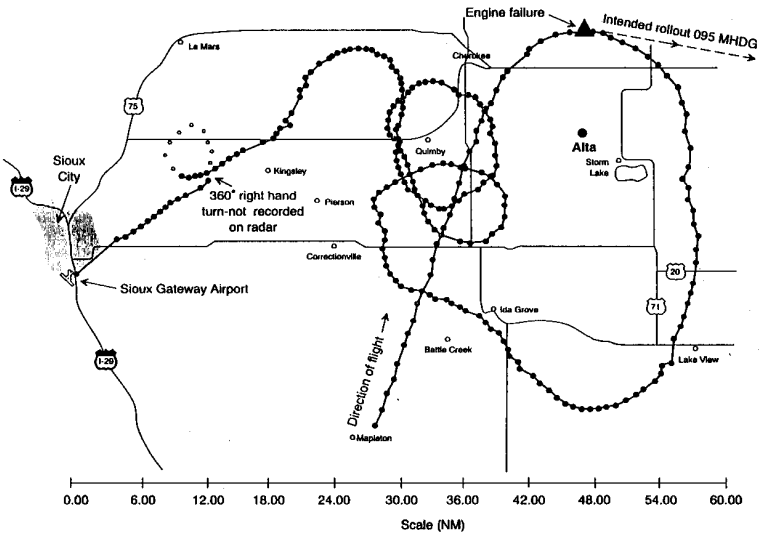

Figure 2.--Ground track from radar plot.

During the final approach, the captain recalled getting a high sink rate alarm from the ground proximity warning system (GPWS). In the last 20 seconds before touchdown, the airspeed averaged 215 KIAS, and the sink rate was 1,620 feet per minute. Smooth oscillations in pitch and roll continued until just before touchdown when the right wing dropped rapidly. The captain stated that about 100 feet above the ground the nose of the airplane began to pitch downward. He also felt the right wing drop down about the same time. Both the captain and the first officer called for reduced power on short final approach.

The check airman said that based on experience with no flap/no slat approaches he knew that power would have to be used to control the airplane's descent. He used the first officer's airspeed indicator and visual cues to determine the flightpath and the need for power changes. He thought that the airplane was fairly well aligned with the runway during the latter stages of the approach and that they would reach the runway. Soon thereafter, he observed that the airplane was positioned to the left of the desired landing area and descending at a high rate. He also observed that the right wing began to drop. He continued to manipulate the No. 1 and No. 3 engine throttles until the airplane contacted the ground. He said that no steady application of power was used on the approach and that the power was constantly changing. He believed that he added power just before contacting the ground.

The airplane touched down on the threshold slightly to the left of the centerline on runway 22 at 1600. First ground contact was made by the right wing tip followed by the right main landing gear. The airplane skidded to the right of the runway and rolled to an inverted position. Witnesses observed the airplane ignite and cartwheel, coming to rest after crossing runway 17/35. Firefighting and rescue operations began immediately, but the airplane was destroyed by impact and fire.

The accident occurred during daylight conditions at 42° 25' north latitude and 96° 23' west longitude.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others	Total
Fatal	1	110	0	111
Serious	6	41*	0	47
Minor	4	121	0	125
None	0	13	0	13
Total	11	285	0	296

*One passenger died 31 days after the accident as a result of injuries he had received in the accident. In accordance with 49 CFR 830.2, his injuries were classified "serious."

1.3 Damage to Airplane

The airplane was destroyed by impact and postcrash fire.

Photographs of the airplane were taken by observers on the ground during its final approach to Sioux Gateway Airport. They showed that the No. 2 engine fan cowling and the fuselage tail cone were missing. The remainder of the No. 2 engine appeared intact. Postcrash examination of the wreckage revealed that the No. 2 engine fan rotor components forward of the fan forward shaft, as well as part of the shaft, had separated from the engine in flight.(See figure 3, figure 4, figure 5).

The airplane's right wing began to break up immediately following touchdown. The remainder of the airplane broke up as it tumbled down the runway. The fuselage center section, with most of the left wing still attached, came to rest in a corn field after crossing runway 17/35.

The cockpit separated early in the sequence and came to rest at the edge of runway 17/35. The largely intact tail section continued down runway 22 and came to rest on taxiway "L." The engines separated during the breakup. The No. 1 and No. 3 engines came to rest near taxiway "L" and the intersection of runway 17/35, between 3,000 and 3,500 feet from the point of first impact.(See figure 6).

The No. 2 engine came to rest on taxiway "J" to the left of runway 22, about 1,850 feet from the point of first impact. The majority of the No. 2 engine fan module was not found at the airport.

The value of the airplane was estimated at $21,000,000.

1.4 Other Damage

Airplane parts, which separated and fell to the ground on cultivated land, caused no significant damage. There was some minor damage to airport facilities and adjacent crops as a result of the crash landing.

1.5 Personnel Information

The flightcrew consisted of a captain, first officer, second officer and eight flight attendants. (See appendix B).

The captain was employed by UAL on February 23, 1956. He had 29,967 hours of flight time logged with UAL, 7,190 hours of which was in the DC-10. He held an airline transport pilot certificate with type ratings in the DC-10 and B-727. He possessed a current first class airman medical certificate. His most recent proficiency check in the DC-10 was completed on April 26, 1989.

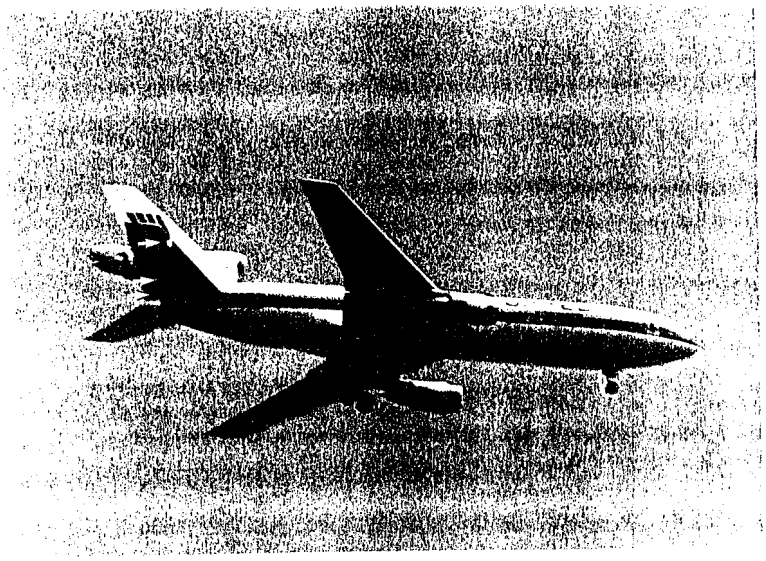

Figure 3.--Photo (C. Zellmer) taken while flight 232 was approaching Sioux Gateway Airport.

Arrows indicate damage to the right horizontal stabilizer. It is also evident that the No. 2 engine fan cowl door and the tail cone are missing.

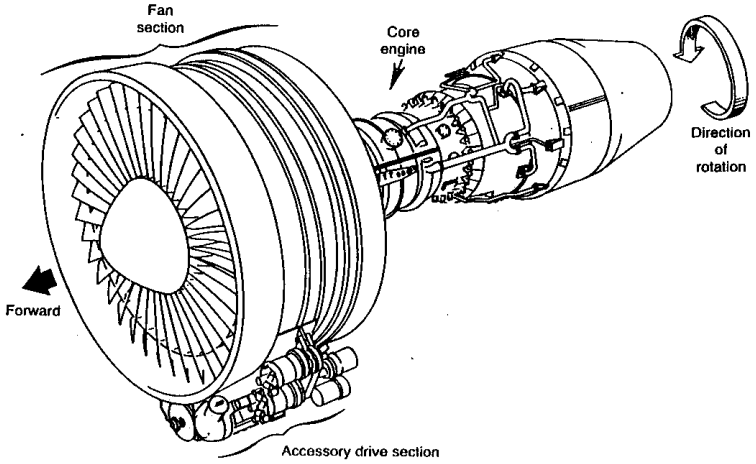

Figure 4.--CF6-6 engine.

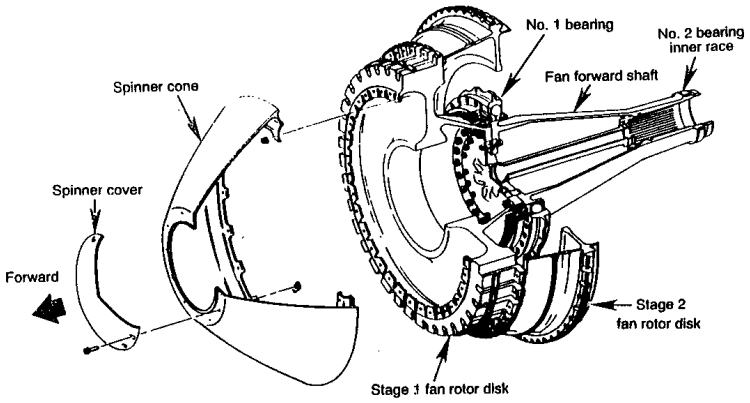

Figure 5.--CF6-6 fan rotor assembly.

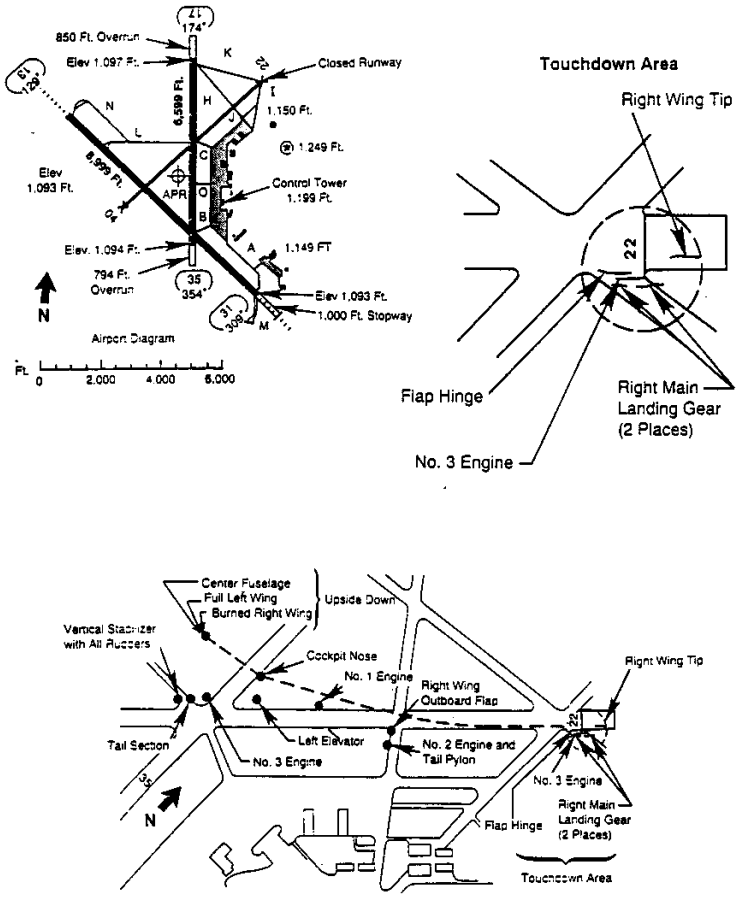

Figure 6.--Sioux Gateway Airport and wreckage path of UA flight 232.

The first officer began airline employment on August 25, 1969. He estimated that he had logged 20,000 hours of flight time. He had accrued 665 hours as a first officer in the DC-10. He held an airline transport pilot certificate with type ratings in the DC-10 and L-1011. He possessed a current first class airman medical certificate. His most recent proficiency check in the DC-10 was completed on August 8, 1988.

The second officer was employed by UAL on May 19, 1986. He estimated that he had 15,000 hours of flight time. UAL records indicated that he had accumulated 1,903 hours as a second officer in the B-727 and 33 hours in the DC-10. He held a flight engineer certificate for turbojet airplanes. He possessed a current second class airman medical certificate. His most recent proficiency check in the DC-10 was completed on June 8, 1989.

A review of flightcrew duty time indicated that the crew had complied with all relevant duty time limitations. The accident occurred on the third day of a 4-day scheduled trip sequence. The crew had a 22-hour layover in Denver prior

to the departure of flight 232. The cockpit crew had flown together six times in the previous 90 days.

The off-duty check airman was employed by UAL on January 2, 1968. He held an airline transport pilot certificate with type rating in the DC-10 and a first class medical certificate. He had completed captain-transition training in the DC-10 on April 25, 1989, and was assigned as a DC-10 training check airman at UAL's Flight Training Center in Denver, Colorado. He had about 23,000 hours total flight time with 2,987 hours logged in the DC-10. He had 79 hours as captain in the DC-10.

1.6 Airplane Information

UAL operated a total of 55 DC-10 airplanes; 47 airplanes were model DC-10-10, and 8 airplanes were model DC-10-30. The accident airplane, N1819U, fuselage No. 118, factory S/N 44618, was delivered in 1971 and was owned by UAL since that time. Prior to departure on the accident flight from Denver on July 19, 1989, the airplane had been operated a total of 43,401 hours and 16,997 cycles.

The maximum certificated takeoff weight for N1819U was 430,000 pounds. The center of gravity (CG) computed for departure was 21.9 percent mean aerodynamic chord (MAC). The calculated CG limits for this gross weight were 13.4 percent and 30.8 percent MAC, respectively. The takeoff gross weight was 369,268 pounds.

The accident airplane was powered by General Electric Aircraft Engines (GEAE) CF6-6D high bypass ratio turbofan engines. The CF6-6 engine was certified by the FAA on September 16, 1970.

Table 1 provides identification and historical information for the engines in N1819U at the time of the accident.

Table 1. Engines Historical Data

Data	Number 1	Number 2	Number 3
Engine Serial Number (ESN)	451-170	451-243	451-393
Total Time	44,078	42,436	39,338
Total Cycles	16,523	16,899	11,757
Time Since Last Maintenance	1,047	2,170	338
Cycles Since Last Maintenance	358	760	116
Time Since Last Shop Visit	3,635	2,170	338
Cycles Since Last Shop Visit	1,318	760	116
Date of Installation	5-9-88	10-25-88	6-11-89

Figure 7 contains a cutaway sectional drawing of the flow path and construction of the CF6-6 engine. The figure also shows the fan and accessory drive sections.Figure 8 displays the CF6-6 rotating assemblies. The portion of the No. 2 engine that departed the airplane is outlined by the dashed lines.

1.6.1 No. 2 Engine Historical Data

Engine S/N 451-243 was first installed on June 23, 1972, in the No. 3 position of a UAL DC-10-10, registration airplane N1814U. Fan module S/N 51406, which contained stage 1 fan disk P/N 9137M52P36, S/N MPO 00385, was installed on engine S/N 451-243 during a shop visit in July 1988, at UAL. At that time, the engine had accumulated 40,266 hours and 16,139 cycles since new.

Engine S/N 451-243 was installed in the No. 1 position on UAL airplane registration N1807U on September 15, 1988. It was removed "for convenience" 8 days later after one flight and was installed in the No. 2 position on N1819U on October 25, 1988. The engine had accumulated 42,436 hours and 16,899 cycles at the time of the accident.

Examination of service records, crew writeups, action items, trend monitoring data, and flight recorder data indicated no abnormal engine operation prior to the in-flight incident, with the exception of certain autothrottle anomalies. The autothrottle system's inability to hold steady N_1 was noted in the reported difficulties, and corrective action entries in UAL's Aircraft Maintenance Information System (AMIS) were dated on July 14, 17, and 19, 1989. On July 19, corrective action for the discrepancy was indicated accomplished at Philadelphia with the replacement of the autothrottle speed control and was signed off as "system ops check normal."

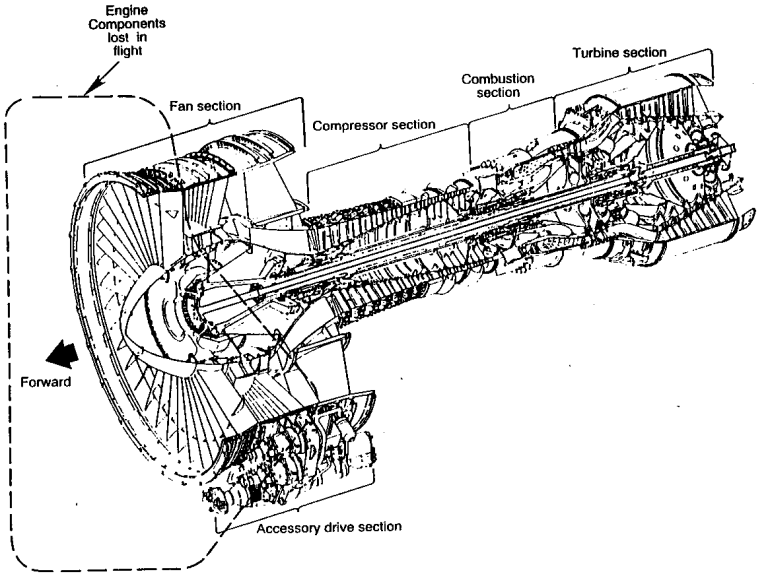

Figure 7.--CF6-6 engine cutaway.

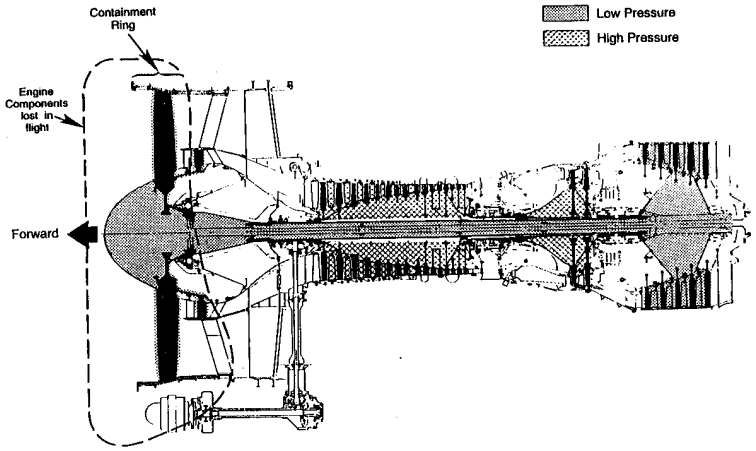

Figure 8.--CF6-6 rotating assemblies.

1.6.2 Stage 1 Fan Disk Historical Data

The stage 1 fan disk, part number (P/N) 9137M52P36,1 S/N MPO 00385, was processed in the manufacturing cycle at the GEAE-Evendale, Ohio, factory from September 3 to December 11, 1971. It was installed as a new part in engine S/N 451-251 in the GEAE production assembly facility in Evendale. The engine was shipped to Douglas Aircraft Company on January 22, 1972, where it was installed on a new DC-10-10.

During the next 17 years, the engines in which this stage 1 fan disk were installed were routinely overhauled and the fan module was disassembled. The disk was removed on the following dates for inspection: September 1972, November 1973, January 1976, June 1978, February 1982 and February 1988. This disk was accepted after each of six fluorescent penetrant inspections (FPI).2 (See figure 9). Five of the six inspections were performed at the UAL CF6 Overhaul Shop in San Francisco, California. One of them was performed at the GEAE Airline Service Department in Ontario, California, in 1973. At the time of the accident, the stage 1 fan disk had accumulated 41,009 hours and 15,503 cycles since new. The last shop visit in February 1988, was 760 flight cycles before the accident, and FPI was performed at that time. The engine had been removed because of corrosion in the high pressure turbine (HPT) stage 1 nozzle guide vanes. At that time, the stage 1 fan disk had accumulated 38,839 hours and 14,743 cycles since new. Following this inspection, the disk was installed in engine S/N 451-243, the No. 2 engine on the accident airplane.

1.6.3 Airplane Flight Controls and Hydraulics--Description

Primary flight controls on the DC-10-10 consist of inboard and outboard ailerons, two-section elevators, and a two-section rudder. Secondary flight controls consist of leading edge slats, spoilers, inboard and outboard flaps, and a dual-rate movable horizontal stabilizer. Flight control surfaces are segmented to achieve redundancy. Each primary and secondary control surface is powered by two of three independent hydraulic systems.

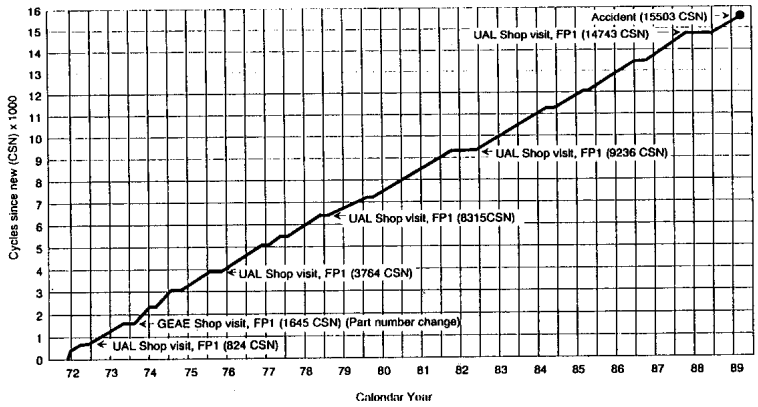

Figure 9.--Inspection history of accident fan disk. (Data source GEAE)

The No. 1 hydraulic system provides power to the right inboard aileron and the left outboard aileron, the right inboard and outboard elevators, the left outboard elevator, the upper rudder, the horizontal stabilizer trim, and the captain's brake system. The No. 2 hydraulic system provides power to the right outboard aileron and the left inboard aileron, the inboard and outboard elevators on the left side, the outboard elevator on the right side, and the lower rudder. It also provides power to the isolated closed-loop system that operates the upper rudder. The No. 3 hydraulic system provides power to the right inboard and outboard aileron and the left inboard aileron, the inboard elevators on the right and left side, horizontal stabilizer trim, and the first officer's brake system. It also drives an isolated closed-loop system that powers the lower rudder actuator. These closed-loop arrangements allow for operation of the remaining parts of hydraulic systems No. 2 and No. 3 in the event of damage to the rudder hydraulic system. (See figure 10).

The three independent, continuously operating hydraulic systems are intended to provide power for full operation and control of the airplane in the event that one or two of the hydraulic systems are rendered inoperative. System integrity of at least one hydraulic system is required--fluid present and the ability to hold pressure--for continued flight and landing; there are no provisions for reverting to manual flight control inputs.

Each hydraulic system derives its power from a separate engine, with a primary and a reserve engine-driven pump providing hydraulic pressure. Either of these pumps can supply full power to its system. Backup power is provided by two reversible motor pumps, which transmit power from one system to another without fluid interconnection. This backup power system activates automatically without requiring flightcrew control, if fluid is still available in the unpowered system.

Electrical power can be used to drive either of two auxiliary pumps provided for the No. 3 hydraulic system. In an emergency situation where the engine-driven pumps are inoperative, an air-driven generator can be deployed into the airstream to supply electrical power to one of these auxiliary pumps.

The hydraulic components and piping are physically separated to minimize the vulnerability of the airplane to multiple hydraulic system failures in the event of structural damage. The No. 1 hydraulic system lines run along the left side of the fuselage to the rear of the airplane and along the front spar of the horizontal stabilizer and the vertical stabilizer. The No. 2 hydraulic system lines are routed from the center engine along the rear spar of the horizontal and vertical stabilizers. The No. 3 hydraulic system lines run along the right side of the fuselage to the tail area and along the rear spar of the horizontal stabilizer. The No. 2 hydraulic system lines are not routed forward of the rear wing spar, in order to isolate them from wing engine fragmentation, and No. 3 hydraulic system lines in the tail section are not routed aft of the inboard elevator actuators in order to minimize exposure to possible engine fragmentation damage from the tail-mounted engine.

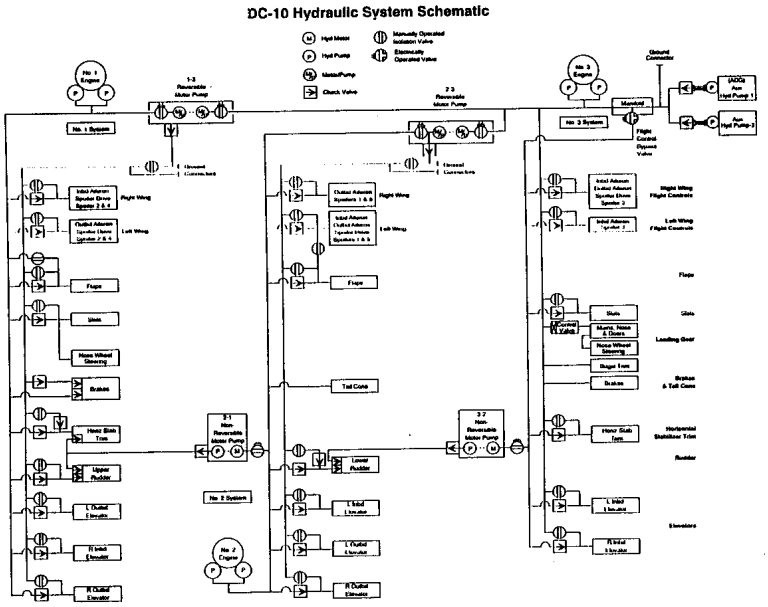

Figure 10.--DC-10 hydraulic system schematic.

The DC-10-10 hydraulic system was designed by the manufacturer and demonstrated to the FAA to comply with 14 CFR 25.901, which in part specified that, "no single [powerplant] failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane...."

1.7 Meteorological Information

The surface weather observation taken at Sioux Gateway Airport at 1559 estimated a ceiling of 4,000 feet with broken clouds and 15 miles visibility. The temperature was 80° F, and winds were 360° at 14 knots. There were towering cumulus clouds in all quadrants. The last wind reported to the crew by the tower at 1558 was from 010° at 11 knots.

1.8 Aids to Navigation

Instrument Landing System (ILS) approaches for runways 31 and 13 were available. When runway 22/04 was closed in 1988, published instrument approaches to that runway were cancelled. Electronic aids to navigation were not used by the crew of UA 232.

1.9 Communications

1.9.1 United Airlines Company Flight Following

At 1521, UA 232 sent an Aircraft Communications and Reporting System (ACARS) message to UAL's central dispatch facility3 in Chicago, Illinois, requesting a call on frequency 129.45. Dispatch was initially unsuccessful in establishing voice contact. At 1523, dispatch initiated an ACARS call to UA 232 that resulted in positive contact.

The communication between UA 232, UAL's dispatch facility and UAL's San Francisco maintenance facility (SAM) was recorded by Aeronautical Radio Incorporated (ARINC). The recording revealed that, at 1525, UA 232 requested that dispatch put the flight in contact with "SAM immediately, it's a MAYDAY." UA 232's initial conversation with SAM occurred at 1527. The crew advised SAM of the loss of all hydraulic systems and quantities and requested whatever assistance SAM could provide. SAM was unable to provide instructions to the flightcrew that they did not already have.

At 1533, SAM informed UA 232 that it was making contact with UAL Flight Operations. At 1540, SAM advised the flightcrew that representatives of UAL's "Operational Engineering" department had been contacted to lend assistance. At 1545, SAM informed the flightcrew that, "Engineering is assembling right now and they're listening to us." UA 232 then advised SAM that the flight was at 9,000 feet and that they were planning to try to land at Sioux City. At 1549, the flightcrew informed SAM that they had just completed the alternate gear extension procedure. This communication was the last one ARINC recorded from UA 232.

The dispatcher working UA 232 stated that UAL Flight Operations asked her to inquire of the flightcrew about the possibility of landing in Lincoln, Nebraska, instead of Sioux City. Flight Operations was concerned about crosswinds and the need for a longer runway. The dispatcher forwarded this inquiry to the flightcrew at 1554 but did not receive a reply.

The dispatch office also received a call from UAL personnel in Sioux City stating that a DC-10 was east of the field experiencing difficulty. Dispatch contacted the Sioux Gateway Airport ATC tower directly and requested the dispatching of all emergency crash, fire, and rescue equipment.

1.10 Airport Information

Sioux Gateway Airport serves Sioux City, Iowa, and is 6 nmi **south** of the city on a flat plain adjacent to the east bank of the Missouri River. Its elevation is 1,098 feet. The airport is owned and operated by the city as a public-use airport.

The airport is currently served by two runways. Runway 17/35, of asphalt construction, is 150 feet wide by 6,599 feet long. Both ends have overruns; 850 feet on the north end and 794 feet on the **south** end. Runway 13/31 is 150 feet wide by 8,999 feet long with 1,000 feet of overrun on the southeast end.

Runway 4/22 has a concrete surface, 150 feet wide by 6,888 feet long. It has paved shoulders 75 feet wide on each side, from the threshold area of runway 22 to the intersection with runway 13/31. Runway 22 has a turf overrun 550 feet long on its approach end, with a short asphalt base section just in front of the threshold. The terrain past the rollout end is cropland. Elevation at the threshold of runway 22 is 1,095 feet. The runway is marked with a yellow "X" painted over the numbers at each end to indicate that the runway is closed.

Sioux Gateway Airport is an "Index B" airport under 14 CFR 139. The airport "INdex" is based on the size of scheduled air carrier aircraft that normally use that facility and the average daily departures of airplanes--in this case--DC-9, B-737, and B-727-100 series airplanes. A full-scale emergency exercise is required under 14 CFR 139 every 3 years, and a "table-top" review of the Airport Emergency Plan is required annually. A mass casualty exercise was conducted at the airport on October 10, 1987, that included the evacuation of about 90 casualties. The most recent drill was conducted on June 16, 1989. During the postaccident discussions, emergency personnel indicated that their preparedness training was a tremendous asset in this response.

DC-10 airplanes are not normally scheduled to land at Sioux Gateway Airport and require the use of an "Index D" airport, which recommends more than twice the quantity of firefighting extinguishing agents required of an "Index B" airport.

Aircraft rescue and firefighting (ARFF) services at the Sioux Gateway Airport are provided by the Iowa Air National Guard (ANG) through a joint-use agreement with the National Guard Bureau, the State of Iowa, and the City of Sioux City. Additionally, the local community reaction plan is coordinated with airport emergency services by the FAA control tower during its hours of operation through the Woodbury County Disaster and Emergency Services Communications Center in Sioux City.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The airplane was equipped with a Sundstrand Model AV557B, serial no. 7510, cockpit voice recorder (CVR) that provided a good record of air traffic control and intracockpit communications for the last 33 minutes and 34 seconds of the flight. The recording began at 1526:42, during a transmission made by the captain to Sioux City Approach Control about 10 minutes after the No. 2 engine had failed.

At 1529:15, the CVR revealed a flight attendant relaying a message to the captain. The captain responded, "okay let'em come up" to the flightdeck. At 1529:35, the check airman arrived on the flightdeck. At 1529:41, the captain explained, "we don't have any controls." Fourteen seconds later, the captain directed the check airman to return to the cabin to determine if he could see any external damage to the airplane through the windows.

At 1530:32, the first officer asked, "What's the hydraulic quantity." The second officer reported that it was zero, followed by the first officer asking, "on all of them," and the second officer confirming the status. The captain followed by saying, "quantity is gone?" Three seconds later, he asked the second officer, "you got a hold of SAM?" The second officer reported, "he's not telling me anything." The captain responded, "we're not gonna make the runway fellas." At this point, it is believed that the check airman returned to the flightdeck, and the captain reported, "we have no hydraulic fluid, that's part of our main problem." The check airman stated, "okay both your inboard ailerons are sticking up that's as far as I can tell. I don't know." He then asked the captain for instructions, and the captain told him which throttle to manipulate. At 1532:02, the check airman reported that the flight attendants were slowly securing the cabin and the captain reported that "they better hurry we're gonna have to ditch I think."

At 1532:16, the captain reported to the approach controller that the flight had no hydraulic fluid and therefore no elevator control and that the flight might have to make a forced landing. Two seconds after the captain began his transmission, the check airman stated, "get this thing down we're in trouble." At 1534:27, the captain decided to attempt a landing at Sioux City and asked the second officer for information to make a no-flap, no-slat landing. He also asked the controller for the ILS frequency heading to the runway and the length of the runway. The controller provided the frequency and reported runway 31 to be 9,000 feet long. At this point, the airplane was about 35 miles northeast of the airport.

At 1535:36, the captain instructed the second officer to start dumping fuel by using the quick dump. At 1537:55, the captain asked the check airman if he could manipulate the throttles to maintain a 10° to 15° turn, and the check airman replied that he "would try." At 1538:55, one of the pilots said that 200 knots would be the "clean maneuvering airspeed," and the first officer responded with, "two hundred and one eighty five on your bugs Al."

At 1540:39, the captain asked the senior flight attendant if everyone in the cabin was ready. The captain explained to the flight attendant that they had very little control of the airplane because of the loss of hydraulic flight controls and that they were going to attempt to land at Sioux City, Iowa. He stated that it would be a difficult landing and that he had doubts about the outcome and the crew's ability to carry out a successful evacuation. He said that there would be the signal "brace, brace, brace" made over the public address system to alert the cabin occupants to prepare for the landing. At 1541:09, the approach controller again informed the flight that emergency equipment would be standing by.

At 1541:52, the second officer reported that a flight attendant said she observed damage on one wing. He asked if he should go aft and look. The captain authorized his absence from the flightdeck to investigate. The second officer returned about 2-1/2 minutes later to report that there was damage to the tail of the airplane, and the captain stated, "... that's what I thought." At 1548:43, the landing gear was extended. At 1549:11, the captain directed the flightcrew to lock their shoulder harnesses and to put everything away.

At 1551:04, ATC reported that the airplane was 21 miles north of the airport. The controller requested the flight to widen its turn slightly to the left in order to make a turn onto its final approach and to keep the airplane away from the city. The captain responded, "whatever you do, keep us away from the city." Several seconds later, the controller gave the flight a heading of 180°. At 1552:19, the controller alerted the crewmembers to a 3,400-foot tower obstruction located 5 miles to their right. The first officer acknowledged. At 1552:34, the controller asked how steep a right turn the flight could make. The captain responded that they were trying to make a 30° bank. A cockpit crewmember commented, "I can't handle that steep of bank...can't handle that steep of bank."

At 1553:35, the first officer stated, "...we're gonna have to try it straight ahead Al..." followed 2 seconds later by the controller advising the crew that if they could hold altitude, their right turn to 180° would put the flight about 10 miles east of the airport. The captain stated, "that's what we're tryin' to do." The first officer then recommended that they try to establish a shallow descent. Twenty seconds later, the captain stated that he wanted to get as close to the airport as possible. Seconds later, he stated, "get on the air and tell them we got about 4 minutes to go." The first officer so advised the controller, but the captain corrected him, saying, "tell the passengers," at which time a crewmember made a PA announcement. At 1555:44, the captain reported a heading of 180°. The controller reported that if the altitude could be maintained, the heading, "will work fine for about oh 7 miles."

At 1557:07, the controller reported to the flight that the airport was "...twelve o'clock and one three miles." At 1558:11, the captain reported the runway in sight and thanked the controller for his help. The captain instructed the second officer

to make a PA announcement, which was believed to be a 2-minute warning. The controller reported the winds as 360° at 11 knots and cleared the flight to land on any runway. At this point, the flightcrew attempted to turn the airplane to the left slightly. At 1558:59, the captain reported, "we're pretty well lined up on this one here...think we will be..." The controller stated that the runway the flight had lined up on was runway 22, which was closed, but he added "that'll work sir, we're gettin' the equipment off the runway, they'll line up for that one." The captain asked its length, and the controller reported it as 6,600 feet long. Twelve seconds later, the controller stated that there was an open field at the end of the runway and that the winds would not be a problem. During the interim seconds, the crew's attention was directed to manipulating the throttles. At 1559:29, one of the crewmembers made the PA announcement to brace for the landing.

At 1559:44, the first of several ground proximity warning system alerts (GPWS) began and ended 8 seconds later. At 1559:58 the captain stated "close the throttles." At 1600:01, the check airman stated "nah I can't pull'em off or we'll lose it that's what's turnin' ya." Four seconds later, the first officer stated, "left Al" followed by "left throttle" left [repeated several times]. A second series of GPWS alerts begin at 1600:09, followed by the first officer stating several times, "we're turning" or "we're tryin." The sound of the impact occurred at 1600:16.

1.11.2 Flight Data Recorder

The flight data recorder (FDR) was a Sundstrand Model 573 (S/N 2159). It was found undamaged, and there was no evidence of excessive wear. The quality of the data recording was generally good, although some anomalies in the data did occur. The recorded data included altitude, indicated airspeed, heading, pitch attitude, roll attitude, stabilizer position, fan rotor speed (N1) for each engine, vertical acceleration, position of control surfaces, longitudinal acceleration, and lateral acceleration.

The FDR contained a full 25 hours of recorded data. The data for the July 19 Denver-Chicago flight and the previous flights on the tape were transcribed and examined for anything unusual in the N_1 record for the No. 2 engine. All prior recorded engine parameters were normal.

The data revealed no evidence of RPM that exceeded the maximum allowable limit of 111 percent N_1 for flights prior to the accident flight. However, the data did reveal cyclic excursions in N_1 within allowable values on all three engines.

The FDR operated normally until ground impact, except for three periods in which the data stream was interrupted and data were lost. The first loss occurred shortly after takeoff during a track switch within the recorder. The second loss of 44 seconds of data occurred approximately 9 minutes before the No. 2 engine failed. The third loss occurred at the time of the No. 2 engine failure, resulting in the loss of approximately 0.7 seconds of data. The FDR data showed that the No. 2 engine failed at 1516:10.

The FDR data for the conditions that existed just prior to the No. 2 engine failure--the last data point before the failure--were:

Pressure Altitude	36.991 feet
Indicated Airspeed	271.25 knots
Total Air Temperature	-17 degrees C.
Magnetic Heading	82.27 degrees
Pitch Angle	2.812 degrees
Bank Angle	20.04 degrees
Fan Speed, No. 1 engine	102.86 percent[4]
Fan Speed, No. 2 engine	102.69 percent
Fan Speed, No. 3 engine	103.59 percent
Vertical Load Factor	1.0556 g's
Longitudinal Load Factor	(+).0708 g's
Lateral Load Factor	(-).0030 g's

[4]Speed is indicated as a percent of a rotor design reference speed. It does not indicate a percent of a rated speed or rated thrust.

1.12 Wreckage and Impact Information

Farm residents in a rural area near Alta, Iowa, notified authorities shortly after the accident to report that aircraft parts had fallen in their area. The aft fuselage tailcone and No. 2 engine parts, including one-half of the fan forward stator casing or containment ring and numerous smaller pieces, were recovered in a relatively localized region the day after the accident.

Also found near Alta soon after the accident were parts of the tail engine adapter assembly, consisting of adapter ring and bellmouth assemblies, an anti-ice pneumatic tube, a starter air tube, three cowl hold-open rods, two hydraulic system accumulators from the No. 2 engine-driven hydraulic pumps, fan blade fragments, two pieces of insulated metal braid-covered hydraulic hose clamped together, and a segment of aluminum material broken out of the large structural "banjo" forging from the airplane inlet duct structure.

Inflight photographs taken by observers on the ground near the airport showed that, to the extent visible from the viewing location, the No. 2 engine installation was still intact, except for the right fan cowl door. The engine mounting beam, reversers, and the core cowl appeared structurally intact prior to ground contact at the airport.

About 3 months after the accident, parts of the No. 2 engine fan disk were found in farm fields near Alta. There were two sections that constituted nearly the entire disk, each with fan blade segments attached. These parts were initially taken to the GEAE facility in Evandale, Ohio, for examination under the direction of the Safety Board. The small segment was later transported to the NTSB Materials Laboratory in Washington for further evaluation. (See section 1.16, Tests and Research).

The recovery location of two pieces of the No. 2 engine stage 1 fan disk assembly relative to the radar track suggested that the small segment of the stage 1 fan disk assembly departed the aircraft to the left, and the remainder of the fan disk assembly departed to the right. Trajectory calculations for the separated fan disk assemblies predicted that, with the northerly winds aloft, both pieces of the fan disk assembly would move to the **south** of the aircraft ground track, where they were actually recovered. (See figure 11).

About 9 months after the accident, farmers in the same area located the front flange of the No. 2 engine rotor shaft and a large section of the fan booster disk. These parts were later examined at the NTSB Materials Laboratory and at other laboratories. (See section 1.16, Tests and Research).

1.12.1 Impact Marks and Ground Damage

The airplane's right wing tip, right main landing gear, and the nacelle for the No. 3 engine contacted the runway during the initial touchdown sequence. The airplane tumbled as it continued down the runway and broke into multiple sections. The airplane skidded off the right side of runway 22 between taxiway "H" and runway 17/35 and through a soybean field. Part of the fuselage and wing section wreckage came to rest in a corn field adjacent to the west side of runway 17/35.

The empennage of the airplane came to rest on its right side against the remaining stub of the right horizontal stabilizer on taxiway "L" near the intersection of runway 4/22 and runway 17/35. Most of the inlet for the No. 2 engine, some of the aft fuselage, a stub of the right inboard horizontal stabilizer, and a part of the vertical stabilizer, just above the engine inlet section, were intact. The separated vertical fin and rudder were located on taxiway "L" just west of the empennage.

The wing center section was found in an inverted position in the corn field and was partially consumed by the postcrash fire. A major portion of the left wing was still attached to the center fuselage. Most of the outboard section of the right wing had separated during the breakup on runway 22. The remainder of the inboard section of the right wing still attached to the center fuselage was heavily damaged by ground impact. The center fuselage section was extensively damaged.

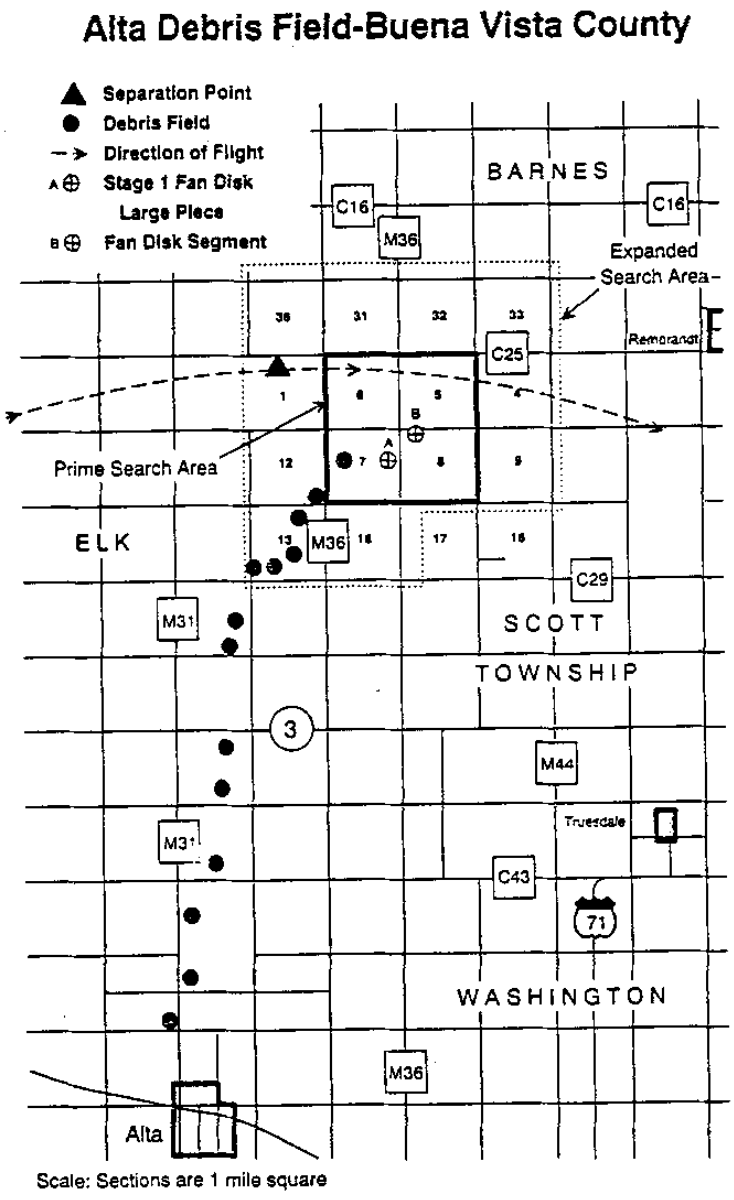

Figure 11. --Trajectory information/Alta debris field.

The forward fuselage section, aft of the crew compartment, had separated and was located near the wing center fuselage section. The crew compartment wreckage was located east of runway 17/35 along the main debris path.

The left horizontal stabilizer separated into three main sections. The pieces were found on the northwest side of runway 22. Two of the sections were located approximately halfway between taxiway "H" and runway 17/35.

The right horizontal stabilizer had broken into a number of pieces, which came to rest on both sides of runway 22. The largest piece recovered was a 16-foot outboard section on the left side of runway 22. Most of the leading edge was missing near the tip. Another large section containing the right stabilizer midsection and portions of the inboard and outboard elevators were recovered on the right side of runway 22 along the debris path.

Portions of the No. 2 engine stage 1 fan blades and stage 2 booster blades were found embedded in aircraft sheet metal of the empennage, and two No. 2 engine fan-to-shaft flange nuts were found lodged in the No. 2 intake acoustic panels.

Four punctures on the vertical stabilizer were noted as probable fragment damage prior to ground impact. Documentation of hole/puncture damage to the horizontal stabilizers is contained in Appendix C. There were 79 punctures recorded from fragment damage and one large hole, about the same size as the large piece of recovered fan disk. The flight control surfaces were recovered in the aircraft wreckage and had varying degrees of damage that could have occurred before or after impact.

Examination of the interior of the empennage revealed that, except for the breached hydraulic fluid systems, there was no evidence of precrash damage to the components comprising the flight control systems, hydraulic systems, or the auxiliary power unit.

Due to extensive ground damage to the airplane structure, continuity of the flight control systems after the accident could not be established for all systems. All control system cables and system component separations that were examined were typical of overload failures associated with ground impact and aircraft breakup.

The extension of the horizontal stabilizer actuators were measured and recorded. Their positions were equivalent to a position of 1° airplane noseup. Measurements of other hydraulically powered flight control actuators were not recorded. These actuators do not have mechanical locking devices and are free to rest or float along with the position of their attached control surfaces, when hydraulic pressure is absent.

The No. 1 engine came to rest on the north side of runway 22 just before the intersection of runway 17/35 and runway 4/22. The engine was located about 3,050 feet beyond the initial impact point of the airplane. The fan cowling for the No. 1 engine had separated shortly after touchdown and was in the soybean field to the left of runway 22 and beyond taxiway "I." The engine had impacted the ground at the 12:00 position5 of the fan module, crushing the forward fan stator case in an aft and radially inward direction into the fan rotor blades. The fan blade airfoils were bent opposite to the direction of rotor rotation.

The No. 3 engine came to rest on the west side of runway 17/35 near the intersection of runway 17/35 and taxiway "L." The engine was located approximately 3,500 feet beyond the initial impact point of the airplane. It had sustained severe ground impact damage. There was no evidence of preimpact damage.

The No. 2 engine came to rest on taxiway "J" to the left of runway 22. The engine was located approximately 1,850 feet beyond the initial impact point of the airplane. It was extensively damaged during the ground impact and from tumbling after it was severed from the empennage.

The upper portion of the aft fan case, upper struts, and the fan frame were still attached to the gas generator core. The aircraft mount beam was still attached to the forward and aft engine mounts. The upper halves of the left and right fan reversers were partially attached at the aircraft mount beam. The exhaust nozzle and centerbody, including the center vent tube, were severely crushed forward into the turbine rear frame. The aft end of the turbine rear frame was also crushed forward over most of its circumference.

The high-pressure compressor cases, the compressor rear frame and the turbine midframe were not visibly damaged. The left quadrant of the upper and lower low-pressure turbine cases were bulging outward in the plane of the stage 5 rotor blades. The stage 5 low-pressure turbine rotor blades were only visible in small regions. In these areas, no contact was observed between the stage 5 blades and the aft side of the stage 5 vanes. The eighth stage bleed air manifolds that were attached to the lower case of the high-compressor stator case were dented.

The aft end of the fan forward shaft, in addition to approximately 20 percent of the shaft cone wall section, remained attached to the engine. Six fragments of the conical section were recovered at the accident site; they represented about 75 percent of the fan forward shaft.

The entire aft fan case with attached fan frame outer struts was recovered at the accident site. Approximately 95 percent of the aft fan stator case was recovered, as well as about 90 percent of the stage 2 fan (booster) inner outlet guide vanes. All of the booster support remained attached to the engine, but the booster stator support was heavily damaged.

Seven sectors of the eight-sector booster midring shroud were recovered at the accident site and contained approximately 60 percent of the midring shroud assembly. All of the sectors were severely deformed and did not show any corresponding evidence of a high-speed rub from the stage 2 booster blades. The shroud sectors displayed irregular rub marks and an irregular rub track. One of the larger shroud sectors contained indentations consistent with booster blade tip impressions radiating outward and forward into the shroud.

Two full and one partial segment of the total of eight stage 1 outlet vane sectors were recovered at the accident site. The partial vane sector contained only the inner band and was found within the left horizontal stabilizer.

The No. 1 ball bearing on the CF6-6 engine is the largest bearing in the engine and is the primary fan support bearing that carries the fan rotor thrust. Fragments from the outer race of the failed engine No. 1 bearing and one bearing ball, in addition to fragments from the No. 2 roller bearing and several intact rollers, were recovered at the accident site. The ball and roller bearings, the raceways and their outer race fragments were not visibly deteriorated and did not exhibit any visual evidence of preaccident spalling or oil starvation.

The fore and aft components of the No. 1 ball bearing housing assembly were recovered at the accident site in front of the No. 2 engine on taxiway "J." Both housings (the forward housing was still attached to the largest fragment of the aft housing) had been separated and deformed into a "horseshoe" shape due to radial outward impact at the 1:00 position.

Two large pieces of one sector of the stage 2 disk assembly (booster spool) were recovered at the accident site. One piece of the assembly consisted of approximately 67 percent of the stage 2 disk's circumference. The other piece consisted of about 32 percent of the forward spacer arm.

Eleven fragments of stage 1 fan blades were recovered at the airport either in the left horizontal stabilizer or on the ground. One fan blade fragment containing the dovetail, platform, and inner airfoil section (S/N AMD 11691) was recovered on the left side of runway 22 between the initial touchdown point and the No. 2 engine position on taxiway "J." It was determined that it was from blade position No. 10.

Sections of 2 of the 20 fan disk/fan forward shaft retaining bolts were recovered during a search of the accident site. The two recovered bolt sections consisted of the shank and head ends only. The thread ends were missing, and the fracture surfaces appeared to be typical of a combination of shear/bending overload.

Three of the 20 fastener nuts for the fan disk/fan forward shaft retaining bolts were recovered at the accident site. Two of these fan nuts were embedded in the No. 2 engine inlet acoustic panels; the third was recovered in the interior area of the right horizontal stabilizer in hole No. 5.

The right and left core cowls had separated from the pylon at their hinge points. The cowls were found 30 feet from the No. 2 engine and were severely damaged by ground impact. The cowl halves were joined by the lower latches; however, the aft hinge had broken.

The lower right half of the forward fan stator case (containment ring) was recovered on the right side of runway 22, approximately 500 feet beyond taxiway "J," and in line with the direction that the empennage had skidded after separating from the fuselage.

1.12.2 Reconstruction of Empennage

The aft fuselage and all identified pieces of the empennage were transported to a hangar at Sioux Gateway Airport for reconstruction (mockup). (See figure 12). The aft fuselage was mounted vertically on a wooden trestle with cables anchoring it to the floor and walls. Lines were strung from the lower surface of the two horizontal stabilizers to the hangar walls to establish the dihedral angles for the horizontal stabilizer reconstruction. The rudder and vertical stabilizer were not used in the reconstruction of the tail. A wooden scaffolding was constructed to support the larger piece of horizontal stabilizer structure, and a wire grid was used to support the smaller pieces. A gallery was constructed around the mockup to aid examination.

Left Horizontal Stabilizer Damage.--All the holes attributed to engine debris damage were examined, and no evidence of severed lines or significant leakage of hydraulic fluid was found.

Right Horizontal Stabilizer Damage.--The outboard elevator had been broken and separated from the outer section of the horizontal stabilizer between the actuator and the inboard damper hinges. Forward of that, the section was broken and had separated on a line parallel to the aircraft centerline from just outboard of the actuator. This section was about 16 feet long. The stabilizer had also separated along a line from between the mid- and inner hinges of the inboard elevator parallel with the aircraft centerline to the leading edge of the stabilizer.

There were three large holes found in the right stabilizer. One hole, located at the outboard leading edge and oriented generally spanwise, extended aft to the front spar; this hole was one of the damaged areas visible in the in-flight photograph taken during the airplane's approach to the airport. Considerable effort was expended to identify the source of this damage; the damage has dimensions similar to the size of the large piece of the fan disk and blades. However, no positive match could be made. A second hole seen in the in-flight photograph was forward of the inboard elevator. Flight control hydraulic components are in this area. The exact size and shape of the hole could not be determined because of damage from the ground impact and the breakaway of the stabilizer section outboard of the inboard elevator actuator. A third hole was in the inboard elevator; there are no critical components within this structure.

Figure 12.--Reconstruction of the tail section of N1819U.

The remaining smaller holes were examined to determine if they had been caused by engine hardware and to verify elements of the aircraft control systems that had been damaged. The diagram shown in appendix C was prepared.

1.12.3 Damage to Inlet Duct and Vertical Stabilizer Spars (Banjo Frames)

Examination of the tail of the airplane revealed crash damage to the front of the No. 2 engine inlet on the right side and top, and the left side was separated at 9:00. The No. 4 (aftmost) section of the banjo frame was cracked through at 3:30, and the aft edge had separated and had a piece missing from 2:30 to 4:00. A portion of the missing piece was recovered from a farm field in the region of Alta, Iowa, and matched the banjo frame from approximately 3:30 to 4:00. The recovered piece was examined and found to contain titanium alloy smears. The only titanium components liberated in flight were from the fan section of the No. 2 engine.

The longitudinal distance between the engine forward fan stator case and the aircraft No. 4 banjo frame (about 17 inches) is bridged by an engine inlet adapter assembly consisting of two cylindrical panels--the inlet bellmouth, bolted to the front flange of the fan forward casing, and the adapter ring. The assembly is designed to provide clearance to accommodate displacement between engine and airframe.

Two pieces of the bellmouth assembly were recovered near Alta, including the area of 7:00 to 12:00. A large portion of this bellmouth panel was torn away at the bracket stations at 9:00 and 11:30. About 25 percent of the inlet adapter ring was eventually recovered.