National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: January 15, 1998

In reply to refer to: A-98-1 and -2

19990210 017

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 3, 1997, about 1948 eastern standard time, a Cessna 650 (Citation III), N553AC, operated by Mercury Communications, experienced an in-flight fire while on approach to the Greater Buffalo International Airport in Buffalo, New York. While descending through 4,000 feet, the crew smelled smoke, a navigation display went blank, and radio communications were lost. After an emergency landing, ground personnel saw flames burning through a hole in the aft fuselage and informed the crew. The flightcrew and passenger evacuated with no injuries; however, the airplane was substantially damaged. The flight was being conducted under the provisions of Title 14 Code of Federal Regulations Part 91 as a corporate flight from Wellsville, New York, to Buffalo.

The Safety Board's investigation revealed that the fire was caused by arcing between 115VAC electrical wiring and the hydraulic pump suction line in the area above the baggage compartment. A fleetwide inspection of Cessna 650s found that nine airplanes had electrical wiring chafing against the same hydraulic line and were at risk of a similar in-flight fire. A subsequent Federal Aviation Administration (FAA) airworthiness directive (AD) required all Cessna 650s to be modified with the installation of an additional clip and five clamps with associated hardware to ensure positive separation between the electrical wires and the hydraulic line.

The Safety Board is aware of other recent incidents caused by inadequate clearance between electrical wiring and adjacent components. On June 25, 1996, Delta Air Lines flight 148, a Boeing 767-300ER (767), experienced a flight control malfunction after taking off from John F. Kennedy International Airport, Jamaica, New York. While climbing through 5,000 feet, the captain heard a loud pop, and the airplane banked sharply to the left. The flightcrew had to deflect the control wheel 25° to the right to maintain a level attitude; a successful emergency landing was made back in New York. The Safety Board's investigation revealed that an aileron flight control cable failed as a result of arcing when it contacted adjacent electrical wiring. Several days later, an aileron cable failure occurred on a 767 operated by Lan-Chile Airlines under similar circumstances. The FAA issued a telegraphic AD for a fleetwide inspection to ensure that 1 inch of clearance existed between the flight control cable and the electrical wiring.

The Safety Board also learned of a 1995 incident aboard a Japan Air Lines (JAL) 767 in which inadequate clearance led to arcing between electrical wiring and an oxygen line fitting near the captain's oxygen mask. This incident was followed by a Boeing service bulletin and an FAA AD mandating the installation of protective sleeving over the wiring within 2 inches of the oxygen lines as an interim protective measure. A July 2, 1997, proposed AD calls for permanent modifications to ensure adequate clearance between oxygen equipment and adjacent wiring.

Based on these accidents/incidents, the Safety Board performed a review of the FAA guidelines for safe wire routing practices. Guidelines were found in two references, Advisory Circular (AC) 43.13-1A, "Acceptable Methods, Techniques, and Practices-Aircraft Inspection And Repair," and AC 65-15, "Airframe and Powerplant Mechanics Airframe Book." (The Safety Board recognizes that these advisory circulars provide general wire routing guidelines and that more specific guidelines may be provided by the manufacturer.) These references state that no electrical wire should be located within 1/2 inch of any combustible fluid or oxygen line, and if the separation is less than 2 inches, back-to-back clamps or a polyethylene sleeve should be installed to ensure positive separation. They also state that electrical wiring should be routed to maintain clearance of at least 3 inches with any control cable. If this clearance cannot be maintained, mechanical guards should be installed to prevent contact between the wiring and the control cables.

The Safety Board reviewed the current company standards and practices used by several manufacturers and found that they do not always provide for the clearance around electrical wiring recommended in the FAA guidelines. For example, Cessna's process specification, "Wiring Installation for Commercial Aircraft," states that wiring shall not be attached to hydraulic lines, and that wiring within 6 inches of hydraulic lines must be firmly supported. However, it does not mention using back-to-back clamps or a polyethylene sleeve to ensure positive separation if the separation is less than 2 inches. Design drawings for the Cessna 650 specify 1/2 inch of clearance between the hydraulic line and electrical wiring but provide no means to ensure positive separation. The Safety Board recognizes that after the Buffalo, New York, accident, the FAA issued an AD to mandate the installation of additional clamps on all Cessna 650s to ensure positive separation. However, the Board is concerned that Cessna's design drawings for the Cessna 650 were not consistent with Cessna's process specifications nor the FAA's guidance.

The Boeing Standard Wiring Practices Manual states that electrical wiring should be routed at least 3 inches away from control cables, if possible. If this cannot be done, rigid support of the wiring must be specified, and if necessary, special mechanical or electrical protection between wiring and control cables should be specified. However, design drawings for the 767 specify only 1 inch of separation between the aileron flight control cable and adjacent electrical wiring, with no mechanical or electrical protection specified; this 1 inch separation did not prevent arcing in the Delta Air Lines and Lan-Chile Airlines incidents. A Boeing service letter and subsequent AD issued after these incidents still require only 1 inch of clearance in this area, with no mechanical guards to prevent contact as recommended in the referenced FAA guidelines.

Finally, the original design of the 767 flightcrew oxygen mask stowage box allowed for electrical wiring to be within 2 inches of oxygen lines, with no protective sleeving over the wiring, as recommended in the referenced FAA guidelines. However, following the 1995 JAL incident, a service bulletin and AD were issued requiring the installation of protective sleeving over the electrical wiring.

The Safety Board concludes that, although not mandated, the FAA guidelines provide adequate protection from the hazards associated with inadequate clearance between electrical wiring and adjacent components. However, the Board is concerned that manufacturers do not always provide this level of protection through their design standards or manufacturing and inspection processes. In some cases, manufacturers are required to modify designs to bring them in line with the FAA guidelines only after an in-service problem or an accident or incident has occurred. To minimize the risks associated with inadequate clearance around electrical wiring, the Safety Board believes that the FAA should review the design, manufacturing, and inspection procedures of aircraft manufacturers, and require revisions, as necessary, to ensure that adequate clearance is specified around electrical wiring, in accordance with published FAA guidelines. In addition, the FAA should review the existing designs of all transport-category airplanes to determine if adequate clearance is provided around electrical wiring, in accordance with published FAA guidelines. If deviations are found, require that modifications be made to ensure adequate clearance.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Review the design, manufacturing, and inspection procedures of aircraft manufacturers, and require revisions, as necessary, to ensure that adequate clearance is specified around electrical wiring, in accordance with published FAA guidelines. (A-98-1)
>
> Review the existing designs of all transport-category airplanes to determine if adequate clearance is provided around electrical wiring, in accordance with published FAA guidelines. If deviations are found, require that modifications be made to ensure adequate clearance. (A-98-2)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: January 21, 1998
In reply refer to: A-98-3 through -5

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On May 12, 1997, at 1529 eastern daylight time, an Airbus Industrie A300B4-605R, N90070, operated by American Airlines as flight 903, experienced an in-flight upset at an altitude of 16,000 feet near West Palm Beach, Florida. During the upset, the stall warning system activated, the airplane rolled to extreme bank angles left and right, and rapidly descended more than 3,000 feet. One passenger sustained serious injuries, and the airplane received minor damage. Flight 903 was being conducted under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121 as a domestic, scheduled passenger service flight from Boston, Massachusetts, to Miami, Florida.

Although the cause of the in-flight upset is still under investigation, the Safety Board has identified several safety issues that it believes the Federal Aviation Administration (FAA) should address.

The A300 is equipped with an electronic flight instrument system (EFIS) that includes two primary flight displays (PFDs), which present airspeed, altitude, attitude, and other information needed to control the airplane, and two navigation displays (NDs), which present heading and other information needed to navigate. These displays are controlled by symbol generator unit (SGU) computers, which process inputs from the various sensors and format the data for display.

During the upset, the captain stated that the EFIS displays were lost for "2 to 3 seconds" and that they were replaced by a white diagonal slash mark across the display screens. This loss of EFIS displays left only the standby indicators available for attitude, airspeed, and altitude reference. The first officer stated that the loss of EFIS displays occurred "when the situation was at its gravest."

Airbus Industrie informed the Safety Board that the diagonal slash marks displayed on the screens during the upset indicated that the SGUs were undergoing an automatic reset and self-test involving software that is designed to detect unreliable data. For example, the SGUs monitor changes in the airplane's flight parameters, such as roll angle, pitch angle, and airspeed. If any of these parameters change at a rate that exceeds a predetermined threshold value, an SGU reset occurs that allows the SGU to perform a self-test for several seconds to determine if the excessive rate-of-change is the result of unreliable data.

The Safety Board learned that the threshold for triggering an automatic reset can be reached during an in-flight upset. For example, if the roll angle rate of change is more than 40° per second, a reset will occur. According to data from the flight data recorder (FDR), flight 903 experienced a change in roll angle in excess of 40° per second during the upset.

The Safety Board is concerned that the loss of all primary flight information during an upset can critically affect a flightcrew's ability to recover the airplane. According to Airbus Industrie, this is the first instance in which an SGU reset was reported during an upset. However, the Safety Board has investigated numerous upsets[1] on large, transport-category airplanes and has a longstanding concern about the need for air carrier pilots to receive training in the recognition of and recovery from unusual attitudes and upsets. In its advanced aircraft maneuvering program, American Airlines teaches pilots (including A300 flightcrews) to recognize various unusual attitudes on their primary flight displays. Loss of information from these displays could adversely affect recognition and recovery from unusual attitudes.

The Safety Board realizes that the intent of the automatic reset feature is to prevent the display of erroneous data to the flightcrew; however, it is concerned that the threshold values selected for activating this feature cause a reset to occur when accurate data is being displayed during an upset. This results in the loss of all primary flight displays at a time when pilots need their critical information the most. Therefore, the Safety Board believes that the FAA should require that Airbus Industrie modify the SGU computer software installed in the A300 so that an unreliable data reset of the EFIS will not occur during an upset. When the modified software is available, the FAA should require that all operators install it in the SGUs.

The effect of SGU failure on the PFDs is outlined in the emergency and abnormal procedures section of the American Airlines A300 Operating Manual. Thus, pilots should recognize that the diagonal slash on EFIS displays results from SGU failure. However, conditions such as the roll rate limitation that produce an SGU failure are not addressed, and the potential for EFIS displays to go blank during maneuvering is not presented in the chapter on unusual attitude recovery. Knowing that the EFIS displays might go blank for several seconds during an upset will better prepare pilots to transfer rapidly to standby instrumentation if an SGU reset occurs during maneuvering. Therefore, as an interim action, the Safety Board believes that the FAA should issue a flight standards information bulletin to direct principal operations inspectors to ensure that A300 operators notify flightcrews of the possibility of a temporary loss of EFIS displays during an upset.

[1]National Transportation Safety Board. 1996. *In-flight Icing Encounter and Loss of Control, Simmons Airlines, d.b.a. American Eagle Flight 4184, Avions de Transport Regional (ATR) Model 72-212, N401AM, Roselawn, Indiana, October 31, 1994.* NTSB/AAR-96/01. Washington, D.C.; National Transportation Safety Board. 1992. *Uncontrolled Collision with Terrain for Undetermined Reasons, United Airlines Flight 585, Boeing 737-291, N999UA, Colorado Springs, Colorado, March 3, 1991.* NTSB/AAR-92/06. Washington, D.C.; National Transportation Safety Board. February 20, 1997. Safety Recommendation Letter. Recommendations A-97-16 through -18.

Another issue raised in this investigation involves the A300 autothrottle system (ATS). The A300 is equipped with an ATS that provides automatic thrust control and can be selected during any flight phase. The ATS can be engaged in several modes, including the speed/Mach mode in which thrust is controlled to maintain the airspeed or Mach number selected by the flightcrew. The ATS is normally engaged via the "A/THR" (automatic throttle) button on the glareshield flight control unit panel. When this button is depressed, three green bars illuminate in it, and the amber "MAN THR" (manual thrust) legend on the flight mode annunciator section of the PFDs is replaced by a green legend corresponding to the selected ATS mode.

Both flightcrew members stated that the ATS was engaged and set to hold an airspeed of 210 knots at the time of the upset. FDR data indicate that the ATS was engaged at the onset of the descent from 24,000 feet. During the descent, the flightcrew moved the power levers from the ATS idle thrust setting to the throttle control lever mechanical stops, slightly reducing the thrust. [This technique is common among A300 crewmembers since it allows the airplane to descend more quickly, and it can be done either with or without disengaging the ATS.] However, when the pilot leveled off at 16,000 feet, FDR data indicate that the ATS was not engaged and that the airspeed began to decrease. As the airplane slowed to about 170 knots, the flightcrew rapidly advanced the throttles, but the stall warning activated and the in-flight upset occurred. Postflight testing found no evidence of ATS malfunction. The Safety Board is concerned that the airplane might have been allowed to decelerate well below the intended airspeed because the flightcrew believed that the ATS was still engaged when it was not.

There are a variety of ways that the ATS can be disengaged when a flightcrew wants manual control of engine thrust. The most common method is to depress the ATS disconnect button on either throttle. This gives the flightcrew manual control of the throttles and causes the ATS mode displayed on the PFD to change to an amber MAN THR indication, and the three green bars in the A/THR button to extinguish.

However, other transport-category airplanes similar to the A300 have been designed with warning systems that require additional flightcrew action to help ensure flightcrew awareness of autothrottle disconnect. For example, after depressing the ATS disconnect button on the McDonnell Douglas MD-11, the ATS disconnects, but a flashing, red "ATS OFF" legend appears on the PFD. This flashing legend continues until the ATS disconnect button is depressed a second time. Other airplanes, such as the Douglas DC-10, MD-80, Boeing 737 (B-737), and Fokker F-100, are designed in a similar fashion. Airplanes, such as the B-757, B-767, and B-777, also sound an aural alert that continues until the flightcrew confirms that they have manual control of the throttles by depressing one of the ATS disconnect buttons a second time.

The A300 indications of autothrottle disconnect are of a passive, persistent nature (an amber MAN THR legend on the PFD and the absence of three green bars in the A/THR button). The Safety Board recognizes that these cues can function as a warning; however, their persistent quality is more typical of an information display and does not command attention. Since pilot attention typically is not drawn to these persistent cues, it is possible for a delay to exist between inadvertent autothrottle disconnect and flightcrew recognition of the event. In contrast, warnings that use flashing displays, aural alerts, or that require positive action to silence, function to capture flightcrew attention and help ensure recognition. Therefore, in light of this accident, the Safety Board believes that the FAA should compare the design of the A300 autothrottle system with similar transport-category airplanes, and determine if additional visual/aural warnings are necessary to ensure that flightcrews are aware that they have manual control of the throttles. If additional warnings are necessary, Airbus Industrie should be required to modify the A300 accordingly.

Therefore, the Safety Board recommends that the Federal Aviation Administration:

Require that Airbus Industrie modify the symbol generator unit (SGU) computer software installed in the A300 so that an unreliable data reset of the electronic flight information system will not occur during an upset. When the modified software is available, require that all operators install it in the SGUs. (A-98-3)

Issue a flight standards information bulletin to direct principal operations inspectors to ensure that Airbus Industrie A300 operators notify flightcrews of the possibility of a temporary loss of electronic flight instrument system displays during an upset. (A-98-4)

Compare the design of the A300 autothrottle system with similar transport-category airplanes, and determine if additional visual/aural warnings are necessary to ensure that flightcrews are aware that they have manual control of the throttles. If additional warnings are necessary, Airbus Industrie should be required to modify the A300 accordingly. (A-98-5)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 3, 1998
In reply refer to: A-98-6

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On August 20, 1997, the left outboard aileron of a Boeing 747-312 (747), operating as Ansett Airlines flight 826, deflected to the full-down position while the airplane was taxiing for takeoff at Brisbane International Airport, Brisbane, Australia. Postincident examination of the aileron control system was conducted by the Bureau of Air Safety Investigation (BASI), Commonwealth of Australia. The examination revealed that one of the left aileron cables (AA-11) that connect the inboard aileron quadrant to the aileron cable drum was broken. An adjacent cable (AB-13) that connects the aileron cable drum to the outboard aileron quadrant via a turnaround pulley was frayed. The aileron cable drum forward guide pin exhibited signs of wear consistent with abrasion by an aileron control cable. The airplane was manufactured in 1983, production line number 590, serial number (S/N) 23029, and had 11,027 cycles and 62,399 hours since new. The airplane had been operated 1,022 flight hours since both cables were replaced on June 2, 1997.

The 747 aileron control system comprises a cable loop system and hydraulic aileron actuators. Rotation of the cockpit control wheel moves cables routed along the rear spar of the wings to provide control inputs to inboard and outboard aileron power control units (PCUs).

Each wing has two AA and two AB aileron cable assemblies (see Figure 1.), one inboard and one outboard. The inboard AA cable run connects the aileron programmer quadrant to the aileron cable drum, and the inboard AB cable run connects the same quadrant to the inboard aileron PCU quadrant. The outboard AA cable run connects the aileron cable drum to the outboard aileron quadrant, and the outboard AB cable run connects the drum to the same quadrant via a turnaround pulley. The aileron cable drum, which is located at wing station (WS) 776.98, is a four-slotted pulley with a guide pin and is used to provide a complete (closed) cable loop to the inboard aileron even if the outboard segment is lost because of malfunction. The guide pin's purpose is to ensure that all four cables remain in the correct pulley slots at all times.

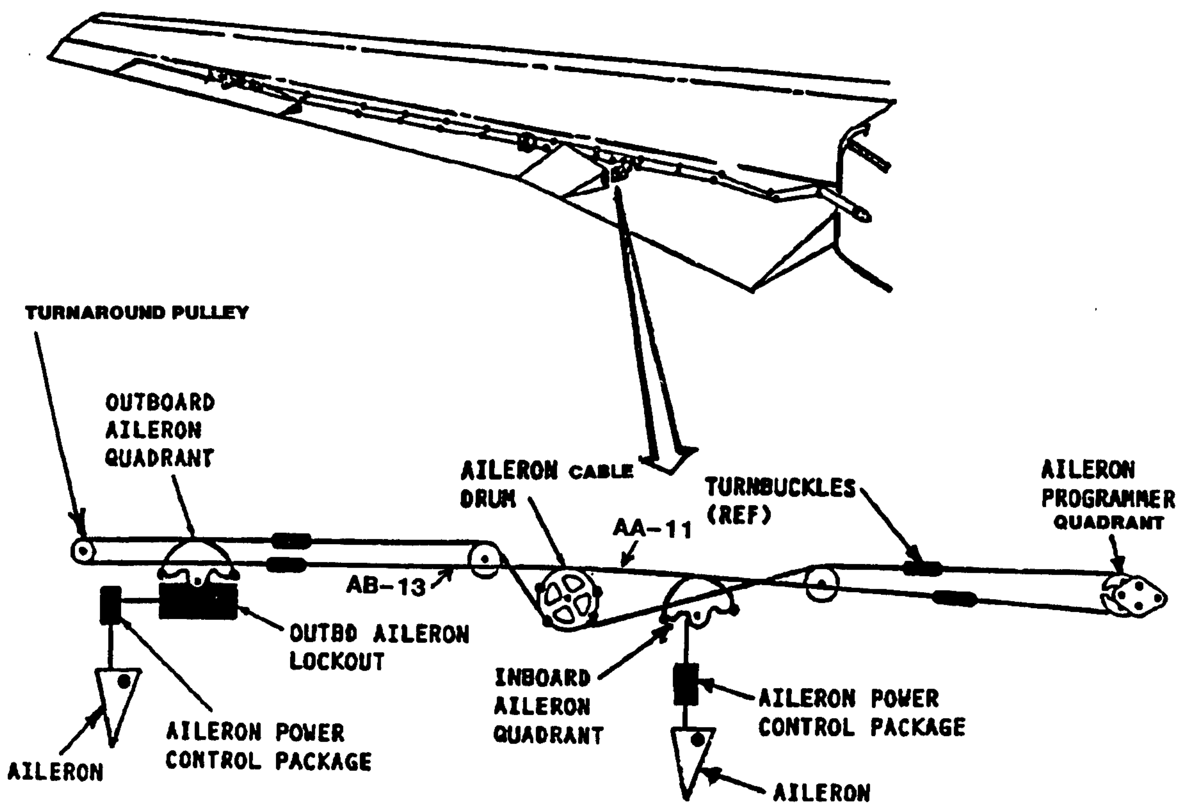

Figure 1. Aileron Wing Control Cable System.

Further investigation by BASI revealed that the two aileron control cable decals[1] on the aileron cable drum's inboard and outboard mounting brackets at WS767 and WS780 were installed incorrectly. The decal for WS767 was fitted at WS780 and vice versa. BASI also found that a similar 747 aircraft, S/N 23028, production line number 584, had the aileron cable replaced because of excessive wear, and the cable was frayed down to one remaining strand. This aircraft also had the two aileron control cable decals on the aileron cable drum's inboard and outboard mounting brackets at WS767 and WS780 fitted incorrectly and interchanged. Because of the decals' transposition, the Safety Board requested a U.S. operator to randomly inspect its 747 airplane aileron control systems for the aileron cable drum decal identification at WS767 and WS780. An inspection on November 24, 1997, of one 747-251, S/N 21707, production line number 378, revealed similar decal transposition on the right WS767 and WS780.

According to Boeing, if these decals are interchanged during installation, the transposition results in incorrect cable routing information at the aileron cable drum and may lead to incorrect cable positioning during installation. A review of the applicable engineering drawings shows that instructions for the decal installations are correct. A check of undelivered 747s at the Boeing factory (production line number 1130 and onward) revealed correct decal installations.

A BASI record review identified eight airplanes from various operators that have had aileron cable installation decals incorrectly installed. Boeing issued Service Letter 747-SL-27-98-

[1] Aileron control system decals are affixed to the airplane in strategic locations to provide illustrative and textual information about the type and routing of cables.

A on May 6, 1991, which addresses the incorrect installation of aileron control cable decals at WS1336.97, and suggests that the operators ensure the cables are properly installed per the applicable drawing. Boeing informed the Safety Board that it is planning to release a service bulletin (SB) to recommend that operators of 747s, produced before production line number 1130, check their airplanes for (1) correct routing of aileron control cables on the aileron cable drum located at WS776.98; and (2) correct installation, and replacement as required, of aileron cable decals at WS767 and WS780.

Boeing's February 8, 1996, In-Service Activities Report 96-02-2711-10 (747) details cable wear occurrences to three other airplanes and attributes the cable wear to misrouting of the cables at the aileron cable drum. Each of the three airplanes had accumulated 40,000-50,000 flight hours and 10,700-11,000 cycles. In each case, the cable appeared to have been chafing on the forward-most guide pin of the aileron cable drum as a result of cable misrouting. The data available regarding these incidents provides no information about whether the installation decals were properly located.

The BASI investigation concluded that the Brisbane incident was caused by misrouting of cables on the aileron cable drum at WS776.98 and that transposition of the aileron control cable decals on the aileron cable drum at WS767 and WS780 has the potential to cause misalignment of the aileron control cables during installation. The Safety Board is concerned that airplanes with mispositioned aileron cable installation decals may be susceptible to aileron cable failures in flight, which could jeopardize flight safety. The Safety Board believes that the Federal Aviation Administration should issue an airworthiness directive to require operators of 747s, produced before production line number 1130, to conduct a one-time inspection of the aileron control system to ensure correct routing of aileron control cables on the aileron cable drum located at WS776.98 and correct installation of aileron cable decals at WS767 and WS780 at the earliest possible inspection interval.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Issue an airworthiness directive to require operators of Boeing 747 airplanes, produced before production line number 1130, to conduct a one-time inspection of the aileron control system to ensure correct routing of the aileron control cables on the aileron cable drum located at wing station (WS)776.98 and correct installation of aileron cable decals at WS767 and WS780 at the earliest possible inspection interval. (A-98-6)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 9, 1998
In reply refer to: A-98-7

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On September 8, 1996, a United Airlines Boeing 737-322, N332UA, experienced what the flightcrew described as severe airframe vibration accompanied by feedback through the rudder pedals after departure from Newark International Airport, Newark, New Jersey. The pilots indicated to the air traffic controller that they would return to the airport and then landed without incident.

While investigating this occurrence, the National Transportation Safety Board was informed of a previous event that had occurred on August 6, 1993. In this event, a United Airlines Boeing 737-300, N340UA, which had departed from LaGuardia Airport, Flushing, New York, encountered intermittent high amplitude vibration in the rudder pedals. The flight diverted to Newark, New Jersey, where it landed without incident.

According to United Airlines, after the first event, N340UA was placed on jacks to simulate the flight mode. It was noted that application of the main wheel brakes caused a kickback or vibration in the rudder pedals. This vibration subsided when either the antiskid system or the "B" system hydraulics were turned off. Also, United Airlines issued an operational alert bulletin to its flightcrews that described the event. United Airlines has attributed the rudder pedal vibrations on both the August 6, 1993, and September 8, 1996, incidents to inadvertent activation by the pilot of the main wheel brakes while in flight.

According to the Boeing Commercial Airplane Group, the antiskid system prevents skidded or blown tires on landing should the pilot inadvertently apply the brakes before touchdown. In the air mode, instability in the brake pedals can occur when the pedals are rapidly depressed, and results in an oscillation of the brake pedals and the rudder.

This condition affects the B-737-300, 737-400, and 737-500 series airplanes. Discussions with Boeing revealed that although the Boeing 737 operations manual states, "...Do not apply brakes after becoming airborne. Braking is automatically applied when the Landing Gear Lever is placed in the UP position...," there is no warning or mention of the possibility of rudder and rudder pedal vibration in the FAA-approved airplane flight manual.[1] In addition, the operations manual does not mention the consequences of applying the brakes in flight or any corrective action necessary to stop rudder pedal vibration that could result from that action. The Safety Board is concerned that as long as this condition exists, it should be appropriately annotated in the FAA-approved airplane flight manual, along with the appropriate corrective actions defined. Therefore, the Safety Board believes that the FAA should require Boeing to make an addition to the FAA-approved airplane flight manual and abnormal procedures to state that severe vibration of the rudder and rudder pedals may be experienced if the main wheel brakes are applied while airborne and to describe corrective action necessary to terminate the vibration, for Boeing 737 airplanes that are subject to braking system vibrations from airborne brake application.

Therefore, the National Transportation Safety Board recommends the following to the Federal Aviation Administration:

> Require the Boeing Commercial Airplane Group to make an addition to the FAA-approved airplane flight manual and abnormal procedures to state that severe vibration of the rudder and rudder pedals may be experienced if the main wheel brakes are applied while airborne and to describe corrective action necessary to terminate the vibration, for Boeing 737 airplanes that are subject to braking system vibrations from airborne brake application. (A-98-7)

Chairman HALL and Members HAMMERSCHMIDT and BLACK concurred in this recommendation. Vice Chairman FRANCIS and Member GOGLIA did not concur.

By: Jim Hall
Chairman

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[1] On some other airplanes it is common practice to apply the brakes shortly after takeoff to stop the main landing gear wheels from spinning in the wheel wells after gear retraction. This action prevents wheel vibration as the wheels spin down to a stop.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

CORRECTED COPY

Date February 13, 1998

In reply refer to: A-98-8

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 23, 1996, a Delta Air Lines McDonnell Douglas MD-88 airplane, N985DL, operating as flight 1593, experienced an uncontained low pressure turbine (LPT) failure[1] in the No. 2 (right) engine during a regularly scheduled Title 14 Code of Federal Regulations (CFR) Part 121 passenger flight from Washington, D.C., to Atlanta, Georgia. The flightcrew reported that while cruising at flight level (FL) 310, they heard a "loud bang" from the No. 2 engine, a Pratt & Whitney (P&W) JT8D-219, serial number (SN) 725978. The engine lost power, followed by a loss of oil pressure and quantity. The pilot shut down the engine, declared an emergency, and diverted to the Raleigh-Durham International Airport without further incident.

Inspection of the aircraft revealed a 3-foot by 1-foot hole in the upper cowling of the No. 2 engine nacelle with no other noted aircraft damage. Examination of the engine revealed that the bolts securing the rear turbine case rear flange to the turbine exhaust case (TEC) front flange had fractured, allowing the two flanges to separate, creating an opening approximately 1-inch wide. Considerable impact damage was observed on the inner diameter of both cases; however, neither case was penetrated. The 4th stage blades exited the engine through the opening between the cases before damaging the engine cowling.

Examination of the LPT revealed that all the 4th stage turbine blades, part number (PN) 798404, were fractured transversely across the airfoil just above the blade root platform, and that the blade roots were retained in the disk. Metallurgical examination of one blade root revealed high cycle fatigue (HCF)[2] that initiated on the convex airfoil side and propagated from 75 to 80 percent through the airfoil before failing in overload. No defects were observed in the fracture

[1] This is the only documented case of an uncontained low pressure turbine blade event occurring in a JT8D-200 engine.

[2] HCF is the mechanism in which cracks propagate an incremental amount from the bending stresses associated with resonant frequency vibration. The vibration can cause rapid crack progression through a component. The failure can occur under normal operational stress after the crack progresses through sufficient cross section of the component.

origin area. Examination of the 4th stage LPT blade shroud notches[3] that were recovered from the exhaust case revealed evidence of extreme notch wear estimated at 0.030 to 0.050 inch in depth.

In response to reports of numerous rear turbine case/TEC attachment bolts fracturing during LPT blade fracture events, P&W issued Service Bulletin (SB) 6149 on January 19, 1994, to provide bolts made of a stronger material. The original bolts, made of Tinidur, a steel alloy, lacked the strength needed to prevent the flanges from separating during an LPT blade failure. The stronger bolt, made of Inconel 718, a nickel alloy, improves the containment capability of the flange. Tinidur bolts were involved in this event.

Two days after this event, on April 25, 1996, another Delta Air Lines, McDonnell Douglas MD-88 airplane, N959DL, operating as flight 591, experienced a contained No. 1 (left) engine LPT failure while climbing from FL 310 to FL 330. The flightcrew reported hearing a "loud bang" from the No. 1 engine, a P&W JT8D-219, SN 725977. The pilot shut down the engine and diverted to Shreveport, Louisiana, where the landing was uneventful and no injuries occurred.

Examination of the LPT revealed that all of the 3rd and 4th stage turbine blades were fractured transversely across the airfoil just above the blade root platform. As in the first incident, metallurgical examination of a 4th stage LPT blade, PN 798404, revealed HCF cracking that originated on the airfoil convex side. No defects were noted at the fatigue origin. No evidence of fatigue was observed on the 3rd stage LPT blades, nor were any 3rd or 4th stage blade shrouds recovered to determine the extent of the shroud notch wear.

Along with the HCF on the 4th stage LPT blades, there were other similarities to indicate a connection between the two events and possible causes. The engine serial numbers were consecutive (725977 and 725978); both engines had approximately the same number of cycles (10,833 and 10,862) at the time of failure; both LPT modules were essentially in the same condition as when they were delivered from P&W, with no repairs performed to the internal components; and both 4th stage LPT blades were PN 789404, which has a thin shroud notch configuration.

The JT8D LPT blade design incorporates a blade tip shroud for structural support and vibration dampening. The blade shrouds interlock to provide stiffness so that they function as a single ring to reduce blade flexing caused by thermal, aerodynamic and centrifugal loads. The shroud notches (contact areas) are coated with PWA 694, which is a cobalt alloy that is a hard temperature and wear resistant material, to help reduce wearing. Worn shroud notch surfaces reduce blade damping and drop the blades' resonance frequency into the engine operating range. This increases the vibratory stresses to levels that can initiate fatigue cracking.

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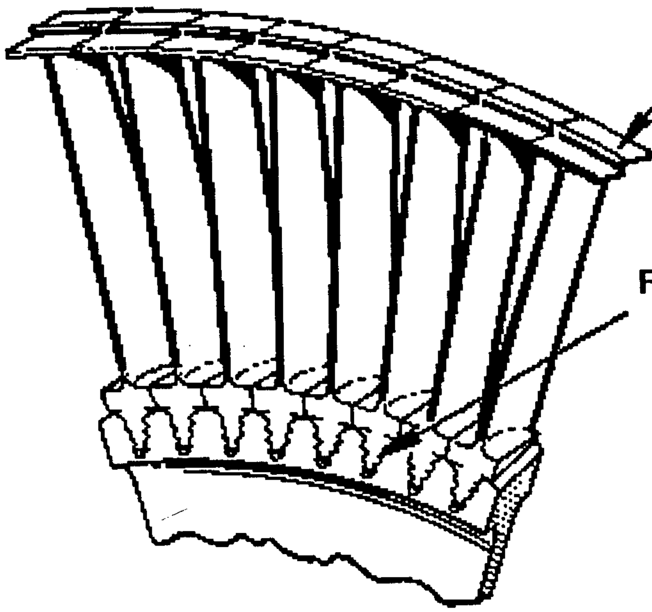
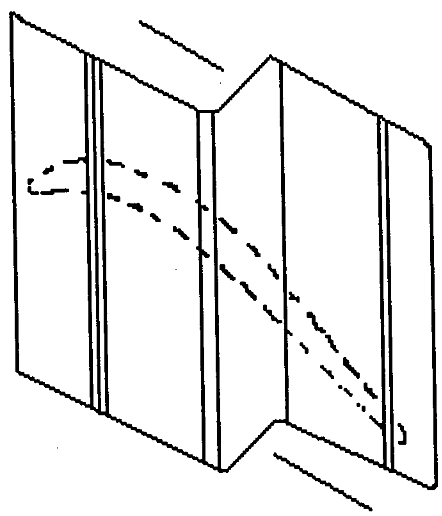
[3] The blade is a casting. The shroud is an integral part of the blade and it is located outboard on the airfoil.





Typical Top View of Blade

According to P&W, the JT8D-200 series engine has experienced 180 3rd and 4th stage LPT blade failures resulting from two different failure modes. The first is excessively worn LPT blade notches that can result in HCF fractures occurring at the root of the 3rd and 4th stage blades. P&W indicated that approximately 95 percent of all 3rd and 4th stage blade failures are the result of worn shroud notches. The second is a low cycle fatigue (LCF)[4] crack initiating in the 4th stage blade shroud fillet resulting in a cross-notch failure.

P&W addressed the wear problem by increasing the blade's shroud notch contact area. The objective was to reduce the notch wear rate and thereby reduce blade failures. Three SBs were issued to introduce new 3rd and 4th stage LPT blade designs. SB 5867[5] was issued on September 22, 1989, to replace the 3rd stage thin shroud notch blade configuration with a blade featuring an increased contact area. There have been only two documented 3rd stage LPT blade failures of this new blade. SBs 6029[6] and 6090[7] were issued on June 18, 1991, and August 6, 1992, respectively, to introduce 4th stage blades with a similar larger contact area. There have been 18 recorded blade failures since the introduction of the two new blades. At a briefing conducted for the FAA and the Safety Board on October 11, 1997, P&W stated that the increased failure rate is due to the addition of more shroud material used for the thick notch. This extra material increased the LCF stresses in the shroud fillet radius resulting in thick notch shroud failures. The blade design was upgraded to reduce the fillet radius stresses so that the shrouds would no longer fracture, but kept the thick notch configuration to address the fractures due to excessive notch wear. P&W issued SB JT8D-6308 on October 10, 1997, to introduce this upgraded 4th stage LPT blade and made it available to the operators in early November 1997. Thus far, there is not yet any operational experience with this current design.

On March 7, 1996, an American Airlines McDonnell Douglas MD-82 airplane, N73444, operating as flight 1853, experienced a contained No. 2 engine failure en route to Orlando, Florida. The flightcrew reported hearing a "loud bang" and experienced a subsequent loss of power in the No. 2 engine, a P&W JT8D-217C, SN 718479. The airplane returned to Chicago, Illinois, without further incident. Engine disassembly revealed that all of the 3rd and 4th stage LPT blades were fractured near the airfoil root. The engine was equipped with the 4th stage LPT blade, PN 808904, that was introduced by SB 6090. The increased blade shroud notch surface on this blade was designed to have eliminated the HCF fractures at the blade root platform that occurred in this event.

From 1973 through 1989, there were 527[8] documented cases of 3rd and 4th stage LPT blade HCF fractures occurring in JT8D-1 through -17AR series engines.[9] The LPT blade failures

[4] LCF is the mechanism in which cracks propagate an incremental amount from the increased pressure, temperature, and centrifugal stresses associated with starting an engine and increasing the thrust to takeoff power.

[5] SB 5867 replaced blade PN 772203 with PN 804303. The change is applicable to -209, -217 and -217A series. There have been 88 documented LPT blade, PN 772203, fractures. This accounted for 85 percent of all 3rd stage -200 blade failures. Approximately 65 percent of the current -200 series engine fleet has PN 804303 blades installed.

[6] SB 6029 replaced blade PN 775404 with PN 804304. The change is applicable to -209, -217 and -217A series. There have been 32 documented LPT blade, PN 775404, fractures. This accounted for 31 percent of all 4th stage -200 series blade failures. Approximately 72 percent of the current -200 series engine fleet has PN 804304 blades installed.

[7] SB 6090 replaced or modified PNs 798404 and 810504 with PN 808904. The change is applicable to -217C and -219 series engines. There have been 27 documented LPT blade, PN 798404, fractures. This accounted for 26 percent of all the 4th stage -200 series blade failures. Approximately 75 percent of the current -200 series engine fleet has PN 808904 blades installed.

[8] This is the number of documented blade failures at the time of the issuance of ASB A5913 on April 2, 1990.

were caused by excessively worn shrouds resulting in 21 uncontained turbine events. To manage the problem, P&W issued an alert service bulletin (ASB), A5913, on April 2, 1990, to perform recurrent inspections for wear on the blade notches for installed 3rd and 4th stage LPT blades. The FAA mandated this action with the issuance of Airworthiness Directives (AD) 94-20-08 and 94-20-09, on November 14, 1994. The inspection uses a mechanical tool made up of a torque screwdriver and notch gauge. The tool is inserted through the exhaust duct and placed between two adjacent 3rd or 4th stage LPT blades. The tool is then rotated to separate the blades, and the amount of torque to do so is recorded. This gives an indication of the amount of wear present on the blade notches. Blades that have worn shrouds require less torque to separate and vice versa. Analysis of the torque check data indicated that the inspection was effective in identifying worn notches before blade failures in JT8D-1 through -17AR series engines.

P&W determined that the same failure mechanism that had occurred in the JT8D-1 through -17AR series was also occurring in the -200 series. Based on the success of the torque check on -1 through -17AR series engines, P&W issued SB 6224 on October 12, 1995, to address the -200 series engines just as ASB A5913 had for the -1 through -17AR series. However, because of differences in blade geometry and operating environment for the -200 series engines, the inspection interval and torque limits were varied. The notch gauges were redesigned, and the number of inspection locations within the 3rd and 4th stage LPT were modified. P&W recommended that the time intervals listed in SB 6224 not be considered hard requirements because the times were based on limited service data and those operators, who had established inspection intervals based on their own experience, are continuing to use their own criteria until operational data results in revised limits. Thus far, there is no information available from the operators that verifies whether the torque check on the -200 series is effective and the proposed inspection interval is appropriate.

Several operators, including American Airlines, Trans World Airlines and Continental Airlines, are using an isotope inspection (x-ray) to determine the amount of wear on the blade shrouds, instead of the torque check. From the x-ray, the blade offset and shroud gap are measured to determine the notch wear. P&W is currently reviewing this technique and the operators' proposed limits, and is collecting data to determine the inspection's effectiveness. Other operators are using shims to measure the gap between blades and to define acceptable wear limits. Each of the techniques mentioned may be effective, but the torque check remains the only P&W-approved procedure for determining the amount of blade notch wear. The lack of operational data on any of these inspection techniques makes determining the appropriate method(s) for measuring the wear difficult.

Worn LPT blade shrouds can result in blade failures causing considerable engine and aircraft damage on JT8D-200 series engines even with the incorporation of the redesigned blades with the thicker shroud notch. The Safety Board concludes that recurrent inspection of the 3rd and 4th stage LPT blades for notch wear is needed to prevent future failures. Therefore, the Safety Board believes that the FAA should determine the effectiveness of inspection techniques used to measure the amount of shroud wear on installed 3rd and 4th stage low pressure turbine

[9] Of the 527 LPT events, 456 were 3rd stage and the remaining 71 were 4th stage. Thirteen of the uncontained events were 3rd stage LPT failures with the remaining 8 4th stage.

blades on P&W JT8D-200 series turbofan engines, and mandate inspection techniques determined to be most effective based on an interval derived from failure and operational data.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Determine the effectiveness of inspection techniques used to measure the amount of shroud wear on installed 3rd and 4th stage low pressure turbine blades on Pratt & Whitney JT8D-200 series turbofan engines, and mandate inspection techniques determined to be most effective based on an interval derived from failure and operational data. (A-98-8)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

CORRECTED COPY

Date: March 4, 1998

In reply refer to: A-98-9 through -23

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On July 6, 1996, at 1424 central daylight time, a McDonnell Douglas MD-88, N927DA, operated by Delta Air Lines Inc., as flight 1288, experienced an engine failure during the initial part of its takeoff roll on runway 17 at Pensacola Regional Airport (PNS) in Pensacola, Florida. Uncontained engine debris from the front compressor front hub (fan hub) of the No. 1 (left) engine penetrated the left aft fuselage. Two passengers were killed, and two others were seriously injured. The takeoff was rejected, and the airplane was stopped on the runway. The airplane, operated by Delta as a scheduled domestic passenger flight under provisions of Title 14 Code of Federal Regulations (CFR) Part 121, with 137 passengers and 5 crew on board, was destined for Hartsfield Atlanta International Airport in Atlanta, Georgia. The JT8D-219 engine was manufactured by Pratt & Whitney. The fan hub was machined, finished, and inspected for Pratt & Whitney by Volvo Aero Corporation in Trollhattan, Sweden, in January 1989. It had accumulated 13,835 cycles at the time of the accident. The service life, or "safe life," of this fan hub was 20,000 cycles.

The National Transportation Safety Board determined that the probable cause of this accident was the fracture of the left engine's front compressor fan hub, which resulted from the failure of Delta Air Lines' fluorescent penetrant inspection (FPI)[1] process to detect a detectable fatigue crack initiating from an area of altered microstructure that was created during the drilling process by Volvo for Pratt & Whitney and that went undetected at the time of manufacture.

[1]FPI is an inspection technique for checking part and component surfaces for cracks or anomalies. The technique involves applying a penetrant fluid (a low viscosity penetrating oil containing fluorescent dyes) to the surface after the part has been cleaned and allowing it to penetrate into any surface cracks. Excess penetrant is then removed and a "developer" is applied to act as a blotter and draw the penetrant back out of any surface cracks. This produces a fluorescent indication of cracks or anomalies when viewed under ultraviolet lighting.

Contributing to the accident was the lack of sufficient redundancy in the in-service inspection program.[2]

Fan Hub Fracture

The investigation revealed that the left engine fan hub fractured radially in two places within a tierod hole[3] early in the takeoff roll when the airplane was at low speed during normal operation. Metallurgical examination of the microstructure underlying the surface of the tierod hole (closest to the hole wall surface) in the origin areas determined that the material was severely deformed and hard. The appearance of the microstructure suggested high frictional heat. Laboratory analysis indicated that the microstructure contained an oxygen-stabilized layer of recrystallized alpha grains[4] adjacent to the surface of the tierod hole. This indicated that the temperature at the surface of the hole in the damaged area had reached at least 1,200°F, the minimum recrystallization temperature for titanium. Iron was also found in this layer of altered microstructure, both widely dispersed and in a high concentration within small isolated bands.

Although stabilized alpha is often associated with an inclusion in the titanium alloy created during the melting or forging process, it can also be formed during machining operations when tools overheat titanium alloy in the presence of air. The location and appearance of the accident hub's altered microstructure indicated that the deformation was formed by a tool used in creating the tierod hole.

Volvo test drillings conducted after the accident produced altered microstructure in two holes, one of which contained features very similar to the accident hub. Test drilling was conducted using a coolant channel drill,[5] but without coolant and at higher drill revolution and feed speeds to promote tool (drill) breakage and the accumulation of chips in the hole. According to Volvo's report, altered microstructure "can be created during rough [initial] drilling, but not during subsequent boring and honing operations."

According to Volvo, the hole with defect features that most resembled those of the accident hub had a microstructure that was "heavily deformed" and that had a hardness that corresponded "with the values for the failed hub." An analysis determined that the layer of

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[2] National Transportation Safety Board. 1998. *Uncontained Engine Failure, Delta Air Lines Flight 1288, McDonnell Douglas MD-88, N927DA, Pensacola, Florida July 6, 1996.* Aircraft Accident Report NTSB/AAR-98-01. Washington, DC.

[3] The aft end of the fan hub attached to the stage 1.5 disk with 24 tierods that passed through tierod holes drilled in the hub rim.

[4] Recrystallization is a formation of a new grain structure from the structure of the deformed metal.

[5] A coolant channel drill has two internal borings that bring coolant/lubricant to the tip of the drill just behind the cutting lips.

deformed microstructure contained ladder type cracking and "a high concentration of iron from the drilling operation."[6]

Because the high temperature (at least 1,200°F) required to form the altered microstructure could not have existed if coolant were flowing freely over the area, the Safety Board considered the possibility that the coolant channel drill malfunctioned. However, because a complete cessation of coolant flow over the hub would have been readily noticeable by the drill operator, the loss of coolant to the area of the altered microstructure was more likely caused by a brief obstruction to the coolant reaching that particular area, such as would result from chip packing or broken pieces of a drill bit. Therefore, chip packing or wedging, leading to a temporary, localized loss of coolant most likely contributed to the creation of the altered microstructure. Thus, the Safety Board concludes that some form of drill breakage or drill breakdown, combined with localized loss of coolant and chip packing, occurred during the drilling process, creating the altered microstructure and ladder cracking in the accident hub. Based on the number of fatigue striations found in the fatigue fracture region, which was roughly equivalent to the number of the hub's flight cycles, the Safety Board further concludes that the fatigue cracks initiated from the ladder cracking in the tierod hole and began propagating almost immediately after the hub was put into service in 1990.

Analysis of Volvo's Inspection Procedures

A blue etch anodize (BEA)[7] test conducted by the Safety Board on the sectioned accident hub revealed a dark blue indication in the areas of the altered microstructure. However, the accident hub passed BEA and visual inspections at Volvo following the drilling process that created the anomalous microstructure. Although the BEA inspector at Volvo noted on a shop traveler[8] that he observed "manufacturing marks" inside a hole, at a subsequent visual inspection inspectors determined that all the holes conformed to Pratt & Whitney acceptance criteria for surface finish on bolt holes. Postaccident metallurgical analysis confirmed that the surface finish in those areas of the tierod hole was consistent with the surface finish requirements specified by Pratt & Whitney. The Safety Board's examination determined that there was no evidence of excessive machining marks at the surface of the hole. It could not be determined whether the BEA inspector made the notation of "manufacturing marks" because of the different surface finish in the tierod hole (boring marks surrounded by honing marks), because of a different coloration resulting from the BEA inspection process, or for some other reason.

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[6]Drill breakdown, for example, could cause minute parts of the drill to shear off during the drilling process.

[7]The BEA inspection process is unique to titanium and involves a visual inspection of the surface after it is anodized (the part surface is electro-chemically oxidized) for anomalies associated with microstructure changes in the metal.

[8]A shop traveler is a process sheet or record that documents inspections or tasks performed on a component.

The Volvo manager who testified during the Safety Board's public hearing stated that the notation by the BEA inspector of "manufacturing marks" in the hole did not signify that the inspector had observed a BEA discrepancy based on the BEA defect templates in use at the time, and he stated that this notation was only intended to alert inspectors conducting subsequent visual inspections with different inspection criteria. Thus, the Safety Board concludes that although the altered microstructure in the accident hub tierod hole was detectable by BEA inspection methods, Volvo did not identify it as rejectable because the appearance of the tierod hole did not match any of the existing inspection templates showing rejectable conditions.

The failure of the manufacturer's BEA inspection to detect and identify a rejectable condition in the accident hub after the drilling process at Volvo resulted in the postaccident development of and addition of four new templates to assist in identifying microstructural defects similar to the accident hub for use by BEA inspectors. The Safety Board recognizes that the BEA inspection process places interpretive demands on inspectors, that identification of rejectable conditions may still not be complete, and that templates of defect indications are added when they are encountered and identified. The Safety Board concludes that although the additional templates will assist BEA inspectors in detecting potential defects similar to the one that existed on the accident hub, this accident suggests that there may be additional rejectable conditions that have not yet been identified. The Safety Board is concerned that these problems may not be unique to parts manufactured by Pratt & Whitney. Therefore, the Safety Board believes that the FAA should form a task force to evaluate the limitations of the BEA and other postmanufacturing etch processes and develop ways to improve the likelihood that abnormal microstructure will be detected. In so doing, it may be appropriate to consider whether any part of these processes can be automated, so as to minimize the possibility of human error.

When Pratt & Whitney approved Volvo's request to use a coolant channel drill, this change was approved because Pratt & Whitney's engineering data indicated that changes in drilling operations were "insignificant" as long as subsequent boring and honing operations were carried out to a depth of at least .010 inch to remove material (including defects) created by the drilling phase. The total depth of material removed from the tierod hole after drilling on the accident hub was about .0185 inch. Metallurgical examinations conducted by the Safety Board after the accident indicated that the total depth of the altered microstructure created by the drill was about .024 inch, more than twice the depth anticipated by the .010-inch limit set by Pratt & Whitney. The Safety Board concludes that drilling damage in this accident hub extended much deeper into hole sidewall material than the depth previously anticipated by Pratt & Whitney. Thus, the Safety Board believes that the FAA should inform all manufacturers of titanium rotating engine components of the potential that current boring and honing specifications may not be sufficient to remove potential defects from holes and ask them to reevaluate their manufacturing specifications and procedures with this in mind.

Failure of Delta Maintenance to Detect Cracking in the Accident Hub

On October 27, 1995, Delta's maintenance facility in Atlanta, Georgia, performed an FPI on the accident hub. This inspection, conducted 1,142 cycles before the accident, was part of overhaul work recommended in Pratt & Whitney's engine shop manual for hubs disassembled from engines before reaching their "safe life" limits.

Postaccident metallurgical examinations conducted by the Safety Board indicated that based on the striation count, at the time of the last FPI, the crack on the aft hub surface adjacent to the tierod hole was about 0.46 inch long and that this crack extended about 0.90 inch within the tierod hole, for a total surface length of 1.36 inches. The FAA's review of FPI processes at Delta concluded that based on reliability data collected by the Nondestructive Testing Information Analysis Center (NTIAC), a visible crack of this size should have been detectable with both a probability of detection and confidence level exceeding 95 percent. The crack was well above the minimum detection length of 0.10 inch as calculated by the NTIAC's Nondestructive Evaluation Capabilities Data Book,[9] and the 0.08-inch and 0.10-inch range suggested in the FAA's December 14, 1990, Titanium Rotating Components Review Team (TRCRT) report. Therefore, the Safety Board concludes that the crack was large enough to have been detectable during the accident hub's last FPI at Delta.

The Safety Board considered the possibility that the crack was not visible during the FPI at Delta. The Safety Board's investigation found that there are a number of ways in which the effectiveness of the FPI process could have been compromised by improperly performed or inadequate procedures. The Safety Board also considered the possibility that the crack was visible at the time of the FPI, but that the FPI inspector either overlooked it or discounted it as insignificant.

Part Cleaning, Drying, Processing, and Handling

The FAA's postaccident report of an August 1996 inspection of the FPI process used by Delta indicated that there was no assurance that parts received by FPI operators were "clean enough for an adequate FPI." The FAA report also noted that cleaning personnel were not made aware of the "criticality of the engine components and the end purpose for which these components were being cleaned." The inspector who inspected the accident hub indicated that he frequently had to send parts back for additional cleaning. The Safety Board recognizes that following the FAA's technical review of Delta's FPI process, Delta indicated that it was providing cleaning personnel with training to emphasize different cleaning procedures for critical parts, especially those being prepared for FPI, and that it was working with engine manufacturers to develop cleaning standards for specific parts. However, the Safety Board is concerned that similar shortcomings may exist at other maintenance facilities performing FPIs.

At the conclusion of the cleaning process in preparation for an FPI at Delta, parts were immersed in a "hot water rinse" and flash dried. Because the dye penetrant applied later in the process has an oil base, any water remaining in cracks would block entry of the dye into those areas. For the flash drying process to be effective, the part must be heated to the temperature of the water, which must be kept at a temperature of between 150° and 200°F, according to Pratt &

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[9] See "Nondestructive Evaluation Capabilities Data Book," Published by the NTIAC, Texas Research Institute Austin, Inc. DB-95-02, May 1996.

Whitney's Overhaul Standard Practices Manual (OSPM) and Delta's Process Standard. A temperature measuring device was not used to determine whether parts had reached the temperature of the water. Rather, according to a Delta representative, operators determined that parts had reached the proper temperature by "feel" and that the water temperature was checked on a weekly basis. After the accident and the FAA inspection, Delta implemented changes requiring more frequent checks of the water temperature.

Delta's director of compliance and quality assurance testified at the public hearing that flash drying may not be effective in areas where water is trapped in areas "that you can't readily see or flaws...." A representative of a company that produces FPI hardware and chemicals testified that "it's absolutely imperative that the parts come to the process clean and dry." Another witness from a company that provided Delta with chemicals for the FPI process stated that the effectiveness of flash drying depends on the depth of the crack. "If it's a fairly deep crack...it's doubtful whether you're going to remove that [water] from a fatigue crack," the chemical company witness stated. Although it could not be conclusively determined whether water trapped in the crack at the time of the FPI rendered the crack undetectable by this method, the Safety Board is concerned that a number of experienced practitioners in the field believe that such a potential exists when flash drying is the only drying method used. The Safety Board concludes that significant questions exist about the reliability of flash drying in removing water from cracks.

With regard to the processing of parts after drying, specifically, the application of developer powder, the Safety Board is concerned that when only a spray gun applicator was used, the powder did not cover the hole walls along the full depth of the hole. The Safety Board is further concerned that even using a more focused application tool, such as a squeeze bulb, the geometry of the hub may be such that full coverage of hole walls may never be possible. Although in this case that deficiency would not have prevented detection of the crack (because there was also a sizable crack on the aft face of the hub), under other circumstances this incomplete coverage may result in nondetection of an otherwise detectable crack. Therefore, the Safety Board concludes that better techniques are needed to ensure the fullest possible coverage of dry developer powder, particularly along hole walls.

Safety Board observers also found that Delta had no formal logging procedure to identify parts ready for inspection (inspection must occur within 2 hours of the application of the developer powder and indications found after 1 hour are considered questionable). Delta representatives indicated that shop personnel relied on a "group knowledge" of how long a part had been ready for inspection.

The time between application of the developer and inspection must be controlled to maximize the brilliance of indications (which increases over time), yet ensure that sufficient dye penetrant remains in the defect for diagnostic activities. Delta inspectors described a method for part tracking in which they coordinated with processors to control the flow of parts so that the time limit would not be exceeded. This informal system would have been vulnerable to error from the difficulty of estimating how long an inspection of the part will take inside the booth, worker distraction, and the potential for the loss of collective knowledge during shift turnover.

Thus, it could not have been possible for Delta personnel to consistently adhere to the development time requirements using this system or to know exactly how long a part had been ready for inspection. The Safety Board is concerned that Delta had timing requirements in its process standard but failed to provide its personnel with a way to adhere to them. Thus, there is no assurance that the accident hub was inspected within the limits set forth in the process standard. Although it could not be conclusively determined whether this played a role in the nondetection of the crack in the accident hub, the Safety Board concludes that the absence of a system that formally tracks the timing of the movement of parts through the FPI process was a significant deficiency. The Safety Board notes that after the accident, Delta implemented a procedure to record part development times on a status board that formalizes part tracking and adherence to time requirements. However, the Safety Board is concerned that other operators and repair stations may not have adequate methods to positively identify the status of parts processed for FPIs.

During the FPI process at Delta, hubs are placed aft-side down on a plastic disk to keep them from contacting the rollers on the FPI line during inspection. Processors and inspectors used their hands to lift and turn the hub on the plastic disk to gain access to the aft-side and interior. During these lifting actions, it would have been difficult for personnel to ensure that they were not touching the hub in an area with an indication, particularly on the aft-face. FPI experts testified at the public hearing that penetrant could be rubbed off during handling. If penetrant was prevented (by dirt or water) from fully entering the crack, then rubbing off the surface penetrant would probably have removed any indication of the crack. But even if penetrant was in the crack, loss or distortion of penetrant at the surface could have resulted in an ill-defined indication, thus making the crack more difficult to detect. Although the extent to which it contributed to the nondetection of the crack could not be determined, the manual handling of the hub at Delta during the processing and inspection of the accident hub increased the opportunity for smearing of an indication on the aft-face. The Safety Board notes that after the accident, Delta advised its FPI personnel to minimize manual handling of hubs and to use support equipment, such as an overhead hoist, in the inspection booth.

The Safety Board previously addressed manual handling and methods to support parts during FPI following a July 19, 1989, accident at Sioux City, Iowa, involving a United Airlines DC-10-10 airplane. That accident was also caused by a crack in a critical rotating engine part.[10] The Safety Board report on that accident stated

> It is possible that the inspector...did not rotate the disk, as it was suspended by a cable, to enable both proper preparation and subsequent viewing of all portions of the disk bore, particularly the area hidden by the suspension cable/hose.

The Safety Board is concerned that deficiencies in the methods for handling critical rotating parts during FPI have been identified in this accident and in the United Airlines accident

[10] National Transportation Safety Board. 1990. *United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux City Gateway Airport, Sioux City, Iowa, July 19, 1989.* Aircraft Accident Report NTSB/AAR-90/06. Washington, DC.

in Sioux City, Iowa. The Safety Board concludes that FPI indications remain vulnerable to manual handling, and fixtures used to support the part during inspection may obstruct inspector access to areas of the part.

Further, the Safety Board concludes that one or more procedural deficiencies in the cleaning, drying, processing, and handling of the part might have reduced or prevented the effectiveness of Delta's FPI process in revealing the crack. The Safety Board also concludes that the potential deficiencies identified in the Delta FPI process may exist at other maintenance facilities and be, in part, the reason for the failure to detect cracks in other failed engines identified in this investigation. Therefore, the Safety Board believes that the FAA should establish and require adherence to a uniform set of standards for materials and procedures used in the cleaning, drying, processing, and handling of parts in the FPI process. In establishing those standards, the FAA should do the following:

1. Review the efficacy of drying procedures for aqueously cleaned rotating engine parts being prepared for FPIs;
2. Determine whether flash drying alone is a sufficiently reliable method;
3. Address the need to ensure the fullest possible coverage of dry developer powder, particularly along hole walls;
4. Address the need for a formal system to track and control development times; and
5. Address the need for fixtures that minimize manual handling of the part without visually masking large surfaces of the part.

Lack of a Formal Method to Ensure Completeness of Search and Diagnostic Followup

To detect the crack on the aft-face of the hub, the inspector would have had to first detect a bright fluorescent green indication (if there was such an indication) against a dark purple background.[11] To detect the indication, the inspector would have had to systematically direct his gaze across all surfaces of the hub. However, systematic visual search is difficult and vulnerable to human error. Research on visual inspection of airframe components, for example, has demonstrated that cracks above the threshold for detection are missed at times by inspectors because they fail to scan an area of a component.[12] Delta FPI inspectors described inspecting major areas on the -219 hub in the same order each time. Although this technique was variable among inspectors and vulnerable to omission, it would help ensure that major areas of the hub were not missed. However, it is possible that the inspector examined the aft-face of the hub but did not look at the specific area containing the indication near the tierod hole.

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[11] The brilliance of an indication is affected by the crack size and amount of penetrant in the defect. Dye penetrant contamination in the work area, processing errors, and methods used to handle and move hubs during the FPI process can also decrease the brilliance of an indication and can affect the inspector's ability to detect a crack.

[12] Department of Transportation. 1996. *Visual Inspection Research Project Report on Benchmark Inspections. Final Report, October 1996.* DOT/FAA/AR-96/95. Washington, DC. This research group advocated development of NDI reliability models that acknowledge a background miss rate unrelated to crack length to more accurately model the observed data.

Interruption is an inherent part of the FPI process, and the inspector would have interrupted his visual search several times to conduct diagnostic evaluations on detected indications and to reposition the hub. It is possible that the inspector failed to resume his search at the last location examined and that he was not aware of this because of the size and complexity of the part.[13] In studies of airframe inspectors, some have failed to detect defects because they did not resume their inspection at the appropriate location after stopping to move equipment.

It is also possible that the inspector detected an indication at the location of the crack but forgot to diagnose, or reinspect, the location. If inspectors had a method to document examined areas and locations requiring followup diagnosis, the inspector's dependency on memory would be reduced. A system in which an inspector could insert plastic markers into holes that have been inspected and found to be defect-free would serve as a mechanical checklist for the inspector and document the progress of the inspection across the part. Such a system would also reduce the opportunity for human error in other procedural inspections, such as eddy current inspections[14] of rivets or holes.

Nondestructive testing (NDT)[15] inspections of critical rotating parts for small flaws are vulnerable to error in visual search and are dependent on the inspector's memory to ensure that an exhaustive search and adequate followup has been conducted. Accordingly, the Safety Board concludes that an inadvertent failure of the inspector to systematically search and complete followup diagnosis when necessary on all surfaces of the hub might have caused the inspector to overlook the crack. Therefore, the Safety Board believes that the FAA should require the development of methods for inspectors to note on the part or otherwise document during an NDT inspection the portions of a critical rotating part that have already been inspected and received diagnostic followup to ensure the complete inspection of the part.

Low Expectation of Finding a Crack and Decreased Vigilance

FPI inspectors are required to diagnose each detected indication to determine if it is a crack because a crack is reason to reject the part. But not every indication is a crack, and most preliminary indications are later found not to be cracks. The inspector who inspected the accident hub stated that he could not recall ever having detected a crack on a -219 hub, and the inspector's supervisor stated that he was not aware that cracks had ever been found on a -219 hub at Delta. Therefore, the inspector's experience diagnosing indications on -219 hubs consisted of a series of false indications. Although the inspector stated that he approached a part as if it had a

[13]It is also possible that the glare associated with the use of white light to diagnose indications contributed to this omission because this process caused his eyes to lose dark adaptation.

[14]Eddy current inspections measure fluctuations in an alternating magnetic field around a part generated by a transducer carrying an alternating current. Eddy current inspections are used to locate surface and near-surface defects.

[15] NDT methods are those that do not damage or significantly alter the component being tested during inspection.

crack to detect, his experience with indications on -219 hubs most likely biased his expectation of confirming that an indication was a crack, especially if the indication was not clearly defined. Therefore, the Safety Board concludes that a low expectation of finding a crack in a -219 series fan hub might have caused the inspector to overlook or minimize the significance of an indication.

A low expectation of finding a crack might also have decreased the inspector's vigilance. Further, research on vigilance suggests that performance decreases with increasing inspection time.[16] However, data to support this conclusion in the aviation inspection domain are inconclusive. In addition, a recent study of eddy current inspection of airframe skin panels found no relationship between inspection duration and probability of defect detection.[17] In any event, no evidence from this investigation exists to evaluate how inspection duration and the adequacy of breaks (the inspector stated he took frequent breaks) affected the inspection of the accident hub. The inspector who inspected the accident hub characterized the FPI process as tedious and monotonous and stated that he spent about 75 percent of his shift inspecting parts. He also stated that inspection of a -219 hub typically took about 40 minutes to 2 hours, depending on the number of indications detected.

The Safety Board concludes that the duration of inspections and the amount and duration of rest periods may indeed affect inspector performance, but this potential has not been adequately studied in the aviation domain. Therefore, the Safety Board believes that the FAA should conduct research to determine the optimum amount of time an inspector can perform NDT inspections before human performance decrements can be expected.

Inadequate Diagnostic Techniques or Controls

It is also possible that the inspector detected an indication at the location of the crack but did not properly complete the followup diagnostic procedure. Diagnostic procedures must be consistently performed and the appropriate time periods must be allowed for redevelopment to ensure that a true defect is not allowed to pass. Delta's Process Standard for conducting FPIs directed inspectors to wait at least 5 minutes to confirm that an indication had not reappeared after developer was applied during the bleedout procedure. As discussed above, there was no formal method for the inspectors to track these indications and to ensure that they were reinspected after the required redevelopment period. Further, no formal method was in place to ensure adherence to the redevelopment time period. The Safety Board anticipates that in establishing the uniform set of standards (recommended above), the FAA will recognize the need for a formal system for measuring and recording development times listed in their process standards for FPI.

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[16] Drury, C. G. 1992. *Inspection Performance, Handbook of Industrial Engineering*. New York.

[17] Department of Transportation. 1992. *Reliability Assessment at Airline Inspection Facilities, Volume III: Results of an Eddy Current Inspection Reliability Experiment. May 1995. Final Report.* DOT/FAA/CT-92/12, III. Washington, DC.

Adequacy of Inspector Training and Proficiency

The Safety Board addressed the issue of NDT inspector training in a previous accident investigation of an uncontained engine failure.[18] In that accident, the Safety Board concluded that a ½-inch crack was present during the last inspection of the disk that would have been detected if proper magnetic particle inspection (MPI) methods had been applied. The Safety Board noted that inspectors at the engine's repair station had trained each other and that the manufacturer had recommended that the repair station develop a formal initial and recurrent training program. In contrast, the Delta FPI inspector had completed a formal training program that included written and practical examinations and his training was consistent with industry standards. However, because this accident revealed that a crack was not detected at a repair facility that followed industry guidance, the Safety Board issued Safety Recommendation A-96-77 on July 29, 1996, asking the FAA to

> Review and revise, in conjunction with the engine manufacturers and air carriers, the procedures, training (including syllabi and visual aids) and supervision provided to inspectors for performing FPI and other nondestructive testing of high-energy rotating engine parts, with particular emphasis on the JT8D-200 series tierod and stress redistribution holes.

The Safety Board classified this recommendation "Open—Acceptable Response" in February 1997, pending final FAA action after the FAA stated that it had inspected Delta's FPI facility and concluded that the airline "had the proper guidance for training and qualifying personnel" in NDT and FPI. The Safety Board's decision was also based on FAA plans to have its FPI Review Team visit six FPI facilities, at a rate of two facilities per month. After the inspections, the FAA stated that it would issue a report and determine what course of action, if any, needed to be taken. The FAA stated that it would also evaluate other facilities that perform FPI and other NDT procedures to determine whether systemic problems existed. The FAA has completed these inspections, but the report has not yet been issued.

A human factors expert testified at the public hearing on this accident that methods have been identified to augment training in inspection. These methods include incremental guidance for specific inspection skills and feedback guidance to inspectors during training. As the FAA completes action on A-96-77, the Safety Board anticipates that the FAA will consider these methods to improve inspector performance.

After the FAA's August 1996 review of Delta's FPI facility, the FAA recommended that written and proficiency examinations be required during inspector recertification. Delta responded to the recommendation by requiring that inspectors pass a written examination on FPI procedural knowledge and receive training to proficiency on a practical examination on a set of 10 sample parts. The Safety Board agrees with the FAA that additional and more frequent

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[18] National Transportation Safety Board. 1996. *Uncontained Engine Failure/Fire, ValuJet Airlines Flight 597, Douglas DC-9-32, N908VJ, Atlanta, Georgia, June 8, 1995.* Aircraft Accident Report NTSB/AAR-96/03. Washington, DC.

evaluation of inspectors is needed to ensure that inspectors are qualified to do their job. Written examinations provide information about an inspector's knowledge of the inspection process and procedures. Proficiency examinations like the one administered at Delta determine whether the inspector can apply the inspection procedures and interpret the results using a limited set of test pieces or actual parts. However, the effectiveness of an inspection involving visual search, like FPI, depends on the inspector's skills in visual search and detection, which cannot be adequately evaluated using written exams and practical tests that do not evaluate the ability of an inspector to detect indications using a sample of representative parts with and without defects. It would be beneficial to evaluate the inspector's skills to detect defects on the line, however, because defects that are missed on actual parts can go undetected. Important feedback information required to determine inspector sensitivity is not available.

The Safety Board concludes that because of the potentially catastrophic consequences of a missed crack in a critical rotating part, testing methods that evaluate inspector capabilities in visual search and detection and document their sensitivity to detecting defects on representative parts are necessary. Such methods would require an inspector to examine several parts, some containing defects and some without, which are representative of those tested on the line. In addition, the defects provided should range in size from small at the threshold for the inspection method to large and well within the method's capabilities. A test of this type would provide an indication on the capabilities of the inspector unlike practical tests on only a few samples or that involve training to proficiency. Further, it would facilitate a comparison of how different inspectors perform and if administered on a frequent basis provide a way to track inspector performance and focus recurrent training. Therefore, the Safety Board believes that the FAA should, in conjunction with industry and human factors experts, develop test methods that can evaluate inspector skill in visual search and detection across a representative range of test pieces, and ensure proficiency examinations incorporate these methods and are administered during initial and recurrent training for inspectors working on critical rotating parts.

Because FPI is dependent on several individuals performing multiple procedures, no single reason for the nondetection of the crack in this accident could be identified. The Safety Board concludes that Delta's nondetection of the crack was caused either by a failure of the cleaning and FPI processing, a failure of the inspector to detect the crack, or some combination of these factors.

Adequacy of Inspection Requirements for Critical Rotating Titanium Components

The Safety Board issued comprehensive recommendations following the United Airlines accident in Sioux City, Iowa, in which an in-flight uncontained engine failure led to the loss of the three hydraulic systems that powered the airplane's flight controls. The investigation found that fatigue cracking in the front fan disk originated in a hard alpha inclusion that had formed during the casting of the disk material. Included in the recommendations were Safety Recommendations A-90-89 and -90, which asked the FAA to develop a damage tolerance inspection program for all engine components that, if they failed or separated, posed a significant threat to the structures and systems of airplanes. In response, the FAA formed the TRCRT to assess the quality control procedures used in the manufacture of titanium alloy high-energy rotating components of turbine engines.

The TRCRT final report made several recommendations related to in-service inspections of titanium rotating parts, including using eddy current inspections to supplement FPIs and a requirement to subject such parts to at least two "subsurface inspections" (e.g., ultrasonic)[19] during their cyclic life. However, the implementation schedule for recommendations contained in the TRCRT report was canceled by the FAA following a 1991 industry conference during which industry representatives requested that the schedule be modified. Based on an April 6, 1993, FAA letter to the Safety Board that stated that future action would be taken to "develop implementation schedules commensurate with the needs of the FAA, industry, and the flying public," the Safety Board classified both safety recommendations "Closed—Acceptable Alternate Action" on May 28, 1993. The Safety Board is disappointed that no new schedules were developed and that no further action was taken by the FAA to implement the recommendations in the TRCRT report.

In addition to this accident, several other uncontained engine failures have occurred after the Sioux City accident and the TRCRT report because of fatigue cracking that initiated from various sorts of microstructural conditions created at manufacture.[20] Further, there was also evidence of manufacturing defects in several engines that failed before the Sioux City accident.[21] This accident history demonstrates that a variety of manufacturing anomalies in a variety of locations on engine parts can lead to uncontained failures, and that manufacturing defects are not as rare as might once have been believed. Further, given the loss of life that has resulted from the Sioux City and Pensacola failures, it is also clear that such defects can pose a significant threat to safety.

Most, if not all, of these engine parts were, at the time of manufacture, subjected to one or more nondestructive inspection techniques (such as an etch, ultrasonic inspection, or FPI) designed to detect manufacturing-related flaws and anomalies that may lead to cracking. (Some of the etch and ultrasonic inspections were performed on the rectilinear part [machine forged

[19]Ultrasonic testing is an NDT method in which high-frequency sound waves are introduced to materials to detect surface and subsurface flaws.

[20]A 1993 failure of the HPC stage 3-9 spool in a CF6-80C2 in Los Angeles, California, was attributed to dwell time fatigue initiating an area of aligned alpha colonies in the titanium alloy; a 1995 failure of an Egypt Air CF6-50C2 engine was attributed to a crack originating at a hard alpha inclusion in stage 6 of the HPC 3-9 stage spool; a 1995 failure of a CF6-50C2B engine in Bangkok, Thailand, was attributed to dwell time fatigue resulting from aligned alpha colonies in the disc bore of the 3-9 HPC; and evidence from a 1997 failure of a Canadian Airlines CF6-80C2B6F engine, which is still under investigation, has revealed a microstructural anomaly in the blade slot bottom of the 3rd-stage HPC 3-9 stage spool.

[21]The 1982 failure of a Pan Am JT8D-7 engine was attributed to a crack originating in altered microstructure in a tierod hole, and three CF6 engine failures occurring in 1974, 1979, and 1983 were attributed to cracking originating in hard alpha inclusions.

shape], and not on the final shape,[22] a practice that is no longer being used.) However, none of the flaws and anomalies that existed in those parts were detected, and the parts passed inspection. This demonstrates that the inspection methods used at manufacture can be fallible, and that newly manufactured engine parts may be placed into service containing potentially dangerous flaws.

Further, many of the flawed engine parts were subjected to in-service FPI or ultrasonic inspections after they developed cracks that had propagated to detectable lengths, yet they were not removed from service.[23] Thus, it is clear that detectable cracks in critical rotating engine parts may escape detection, even though the part has undergone in-service nondestructive testing techniques such as FPI. This point is further demonstrated by the ValuJet uncontained engine failure in Atlanta which, although it did not involve a manufacturing defect, again shows that a critical rotating part with a detectable crack can successfully pass through an NDT process (in that case magnetic particle inspection)[24] and be placed back into service. Probability of detection data confirm that even assuming the FPI procedures are properly executed, some detectable cracks will be missed. However, because FPI procedures may not always be properly carried out, there are several additional reasons why a detectable crack may be missed during the FPI process.

The Safety Board concludes that manufacturing and in-service inspection processes currently being used do not provide sufficient redundancy to guarantee that newly manufactured critical rotating titanium engine parts will be put into service defect-free and will remain crack-free through the service life of the part. The Safety Board agrees with the TRCRT conclusion that

> [based on the] frequency of occurrence of titanium metallurgical defects, the difficulty of detecting defects in titanium,...the many sources of defects, errors and damage, recent developments in the engineering science of fracture mechanics (crack propagation) analysis...the random approach of inspections of opportunity is not adequate, and can no longer be justified.

In light of the above, the Safety Board is especially concerned that the FAA's initial and recurring inspection program, as outlined in Airworthiness Directive (AD) 97-02-11 and a subsequent final rule addressing the intent of Safety Recommendation A-96-74 (by taking into account the potential for microstructural defects produced by standard drills after a "major event such as tool breakage"), does not include mandatory or fixed-interval repetitive inspections for the remaining population of 2,272 fan hubs urged in Safety Recommendation A-96-75.

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[22]For example, the parts involved in the Sioux City, Egypt Air, and Canadian Airlines accidents were etched only in their rectilinear shape and were subjected to FPI in their final shape.

[23]In addition to the fan hub involved in this accident, the parts involved in the 1989 Sioux City, 1995 Egypt Air, 1982 Pan Am, 1995 Thailand, and 1997 Canadian Air accidents all underwent in-service FPI.

[24]MPI is an NDT testing method that uses part or surface magnetization to locate surface and subsurface effects.

The Safety Board is concerned that JT8D-200 series fan hubs with more than 4,000 CSN may not receive FPI and eddy current inspections when these fan hubs are in the shop because there is no requirement to disassemble hubs to the piece-part level. In addition, AD 97-02-11 imposed no inspection requirement before retirement at 20,000 cycles in service (CIS) on fan hubs that have accumulated over 10,000 CIS before March 5, 1997, which constitutes a large percentage of all JT8D-200 series fan hubs. As such, AD 97-02-11 does not require the population of JT8D-200 series fan hubs with holes produced with standard drills or hubs with no machining or dimensional anomalies to be inspected unless the engine is disassembled to the piece-part level. This approach remains unacceptable.

However, the Safety Board's concern is not limited to JT8D-200 series fan hubs, but extends to all critical rotating titanium engine components. The Safety Board concludes that all critical rotating titanium engine components are susceptible to manufacturing flaws and resulting cracking and uncontained engine failures that could potentially lead to catastrophic accidents. Therefore, the Safety Board believes that the FAA should require that all heavy rotating titanium engine components (including the JT8D-200 series fan hubs) receive appropriate NDT inspections (multiple inspections, if needed) based on probability of detection data at intervals in the component's service life, such that if a crack exists, but is not detected during the first inspection, it will receive a second inspection before it can propagate to failure. In developing the inspection intervals, the Safety Board urges the FAA to assume that a crack may begin to propagate immediately after being put into service, as occurred in this accident and the United Airlines accident at Sioux City.

The Safety Board recognizes that all necessary probability of detection data and crack propagation rates may not be immediately available, and may have to be developed for some components. Therefore, the Safety Board believes that the FAA should require, as an interim measure, pending implementation of Safety Recommendation A-98-19, that critical rotating titanium engine components that have been in service for at least 2 years receive an FPI, eddy current, and ultrasonic inspection of the high-stress areas at the engine's next shop visit or within 2 years from the date of this recommendation, whichever occurs first.

These recommendations supersede Safety Recommendations A-96-74 and A-96-75, which the Safety Board now classifies "Closed—Unacceptable Action/Superseded."

Maintenance Deficiencies

During the preflight inspection the first officer found a small amount of oil on the bullet nose of the left engine and two rivets missing from the left wing. The oil that was found on the bullet nose could not have been related to the hub failure, and the missing rivets were from an outboard section of the wing. Therefore, the Safety Board concludes that these were not factors in the subsequent engine failure.

However, the Safety Board is concerned that the flightcrew did not request maintenance action before departure from Pensacola and that flightcrews may generally be reluctant to request maintenance at airports without company maintenance facilities because the reporting process and arranging for contract maintenance may result in delays. In this instance, the captain's deferral of a maintenance check of the oil leak until after arrival in Atlanta and his failure to ensure that maintenance action was taken on the missing rivets appear to have been contrary to guidance contained in Delta's Flight Operations Manual (FOM), which required flightcrews to notify Delta maintenance personnel of maintenance irregularities, or fluid leaks, at the gate. However, the flightcrew's decision was later supported by Delta management. This suggests that Delta management does not agree that fluid drops on the bullet nose or two missing rivets constitute maintenance irregularities.

Thus, the Safety Board concludes that there is a lack of clarity in written guidance in the FOM to Delta flightcrews on what constitutes maintenance "discrepancies" and "irregularities" and when to contact maintenance personnel and to log anomalies. Therefore, the Safety Board believes that the FAA should require Delta Air Lines to review its operational procedures, with special emphasis on nonmaintenance stations, to ensure that flightcrews have adequate guidance about what constitutes a maintenance irregularity or discrepancy (including the presence of fluid drops in unusual locations) before departure, and that following this review Delta should, contingent on FAA approval, amend its FOM to clarify under what circumstances flightcrews can, if at all, make independent determinations to depart when maintenance irregularities are noted. Further, the Safety Board is concerned that similar situations may be encountered by flightcrews at other airlines. Therefore, the Safety Board believes that the FAA should have its principal operations inspectors review these policies and procedures at their respective operators to clarify, if necessary, these flightcrew responsibilities.

Crew Actions and Survival Factors

Immediately following the engine failure, the circumstances in the aft cabin were markedly different than those in the forward cabin. The aft flight attendants were presented with structural damage, serious injuries, and an engine fire, any one of which was sufficient to initiate an evacuation pursuant to Delta's policy and procedures. In contrast, the cockpit crew and forward flight attendant were unaware of these circumstances and, based on the absence of any indications of fire, the captain determined that an evacuation was not warranted. Unaware that passengers were evacuating, the captain did not shut down the engines until the first officer alerted him to do so after having walked through the cabin to assess the situation.

The interphone system was inoperative at the critical moment when decisions were being made by the aft flight attendants to evacuate and by the captain not to evacuate. Thus, neither of these decisions, nor the information on which they were based, could be immediately communicated to crewmembers at the opposite end of the airplane. By the time emergency electrical power was restored to the interphone and the first officer again attempted to contact the aft flight attendants, the flight attendants were no longer in a position to, and would not have been expected to, respond to calls over the interphone because they were carrying out the evacuation and attending to injured passengers.

The Safety Board concludes that neither the aft flight attendants' decision to evacuate nor the captain's decision not to evacuate was improper in light of the information each of them had available at the time. However, the Safety Board is troubled by the lack of communication among crewmembers in the front and back of the airplane. Specifically, the Safety Board is concerned that crewmembers in the cockpit were unaware that emergency conditions existed and an evacuation was ongoing in the rear of the airplane. Even if this information would not have affected the captain's determination not to evacuate the entire airplane, at the very least it likely would have prompted him to immediately shut down the engines to minimize the hazards to those passengers who were evacuating.

The Safety Board has long been concerned about the difficulties that can arise when normal means of communication (interphone and/or public address systems) become unavailable during an emergency situation, when they generally are most needed. Evacuation decisions, which must often be made very quickly, should be based on the most complete information possible about the condition of the airplane and possible hazards. As noted in an accident report on the December 20, 1995, accident involving Tower Air flight 41 at JFK International Airport,[25] "positive communications are essential to coordinate the crew's response, even if the decision is not to evacuate."

In 1972 and 1981 the Safety Board recommended that the FAA require independently powered evacuation alarm systems. However, at that time, the FAA determined that the cost of installing such alarm systems "would far outweigh any identifiable safety benefits." Thus, in most airplanes today, if there is a loss of airplane electrical power, crewmembers and passengers in one part of the airplane may not be aware of an evacuation that is occurring in another part of the airplane. Because a decision to evacuate generally indicates that there may be a hazard to passengers if they remain on board, the Safety Board remains concerned that the lack of an independently powered evacuation alarm system on most airplanes is a significant safety deficiency that should be corrected.

The Safety Board concludes that every passenger-carrying airplane operating under 14 CFR Part 121 should have a reliable means to ensure that all crewmembers on board the airplane are immediately made aware of a decision to initiate an evacuation. Therefore, the Safety Board believes that the FAA should require that all newly manufactured passenger-carrying airplanes operated under 14 CFR Part 121 be equipped with independently powered evacuation alarm systems operable from each crewmember station. The FAA should also require carriers operating airplanes so equipped to establish procedures, and provide training to flight and cabin crews, regarding the use of such systems. The issue of retrofitting existing airplanes with such systems will be addressed in the Safety Board's upcoming evacuation study.

As illustrated in this accident, emergency exits are sometimes opened by passengers before any evacuation order has been given or any decision has been reached. It is important for cockpit crews to know that exits have been opened for any reason so that appropriate measures

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[25] National Transportation Safety Board. 1996. *Runway Departure During Attempted Takeoff, Tower Air Flight 41, Boeing 747-136, JFK International Airport, New York, December 20, 1995.* Aircraft Accident Report NTSB/AAR-96/04. Washington, DC.

can be taken to minimize the resulting potential hazards to passengers who may be departing the airplane through those exits. The Safety Board is aware that some airplanes, including the MD-88, are equipped with cockpit indicators showing open exits, but the Safety Board concludes that safety could be enhanced if all cockpit crews were immediately made aware of when exits are opened during an emergency. Therefore, the Safety Board believes that the FAA should require that all newly manufactured airplanes be equipped with cockpit indicators showing open exits, including overwing exit hatches, and that these cockpit indicators be connected to emergency power circuits. The issue of retrofitting existing airplanes will be addressed in the Safety Board's upcoming evacuation study.

Finally, the Safety Board is concerned that the overwing exits were opened while the airplane was still moving. The passenger who opened that exit told Safety Board investigators that he was uncertain whether he should open the exit and wished that he had received some guidance as to when it should be opened. The "Passenger Safety Information" card made available to each passenger on the Delta MD-88 illustrates how to open the exits, and states that persons seated in emergency exit seats must be able to "[a]ssess whether opening the emergency exit will increase the hazards to which passengers may be exposed." However, the card does not specifically state when the exit should be opened or describe the conditions under which doing so might increase the hazards to which passengers might be exposed. Nor does the card state that the exit should not be opened until the airplane has come to a stop. The Safety Board concludes that the guidance provided to passengers on Delta Air Lines MD-88s regarding when emergency exits should and should not be opened is not sufficiently specific. The Safety Board is also concerned that guidance provided by other airlines on other airplanes might be similarly vague. The Board will address this issue further in its upcoming evacuation study.

As a result of the investigation of this accident, the National Transportation Safety Board recommends the following to the Federal Aviation Administration:

> Form a task force to evaluate the limitations of the blue etch anodize and other postmanufacturing etch processes and develop ways to improve the likelihood that abnormal microstructure will be detected. (A-98-9)
>
> Inform all manufacturers of titanium rotating engine components of the potential that current boring and honing specifications may not be sufficient to remove potential defects from holes and ask them to reevaluate their manufacturing specifications and procedures with this in mind. (A-98-10)
>
> Establish and require adherence to a uniform set of standards for materials and procedures used in the cleaning, drying, processing, and handling of parts in the fluorescent penetrant inspection process. In establishing those standards, the FAA should do the following:
>
>> Review the efficacy of drying procedures for aqueously cleaned rotating engine parts being prepared for fluorescent penetrant inspections; (A-98-11)

Determine whether flash drying alone is a sufficiently reliable method; (A-98-12)

Address the need to ensure the fullest possible coverage of dry developer powder, particularly along hole walls; (A-98-13)

Address the need for a formal system to track and control development times; (A-98-14) and

Address the need for fixtures that minimize manual handling of the part without visually masking large surfaces of the part. (A-98-15)

Require the development of methods for inspectors to note on the part or otherwise document during a nondestructive inspection the portions of a critical rotating part that have already been inspected and received diagnostic follow up to ensure the complete inspection of the part. (A-98-16)

Conduct research to determine the optimum amount of time an inspector can perform nondestructive testing inspections before human performance decrements can be expected. (A-98-17)

In conjunction with industry and human factors experts, develop test methods that can evaluate inspector skill in visual search and detection across a representative range of test pieces, and ensure proficiency examinations incorporate these methods and are administered during initial and recurrent training for inspectors working on critical rotating parts. (A-98-18)

Require that all heavy rotating titanium engine components (including the JT8D-200 series fan hubs) receive appropriate nondestructive testing inspections (multiple inspections, if needed) based on probability of detection data at intervals in the component's service life, such that if a crack exists, but is not detected during the first inspection, it will receive a second inspection before it can propagate to failure; assuming that a crack may begin to propagate immediately after being put into service, as it did in the July 6, 1996, accident at Pensacola, Florida, and in the July 19, 1989, United Airlines accident at Sioux City, Iowa. (A-98-19)

Require, as an interim measure, pending implementation of Safety Recommendation A-98-19, that critical rotating titanium engine components that have been in service for at least 2 years receive a fluorescent penetrant inspection, eddy current, and ultrasonic inspection of the high-stress areas at the engine's next shop visit or within 2 years from the date of this recommendation, whichever occurs first. (A-98-20)

Require Delta Air Lines to review its operational procedures, with special emphasis on nonmaintenance stations, to ensure that flightcrews have adequate guidance about what constitutes a maintenance irregularity or discrepancy (including the presence of fluid drops in unusual locations) before departure, and that following this review Delta should, contingent on FAA approval, amend its flight operations manual to clarify under what circumstances flightcrews can, if at all, make independent determinations to depart when maintenance irregularities are noted. Further, the FAA should have its principal operations inspectors review these policies and procedures at their respective operators to clarify, if necessary, these flightcrew responsibilities. (A-98-21)

Require that all newly manufactured passenger-carrying airplanes operated under 14 Code of Federal Regulations Part 121 be equipped with independently powered evacuation alarm systems operable from each crewmember station, and establish procedures and provide training to flight and cabin crews regarding the use of such systems. (A-98-22)

Require that all newly manufactured airplanes be equipped with cockpit indicators showing open exits, including overwing exit hatches, and that these cockpit indicators be connected to emergency power circuits. (A-98-23)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 26, 1998
In reply to refer to: A-98-24

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On November 24, 1996, the flightcrew of Northwest Airlines (NWA) flight 211, an Airbus A-320-211, N310NW, experienced stiff rudder pedals approximately 50 feet above the ground before landing at Detroit Metropolitan Airport, Michigan. The flight, which was operating under the provisions of Title 14 Code of Federal Regulations Part 121 as a regularly scheduled passenger flight from Ft. Lauderdale, Florida, to Detroit, landed without further incident. The 6 crewmembers and 141 passengers were not injured. Instrument meteorological conditions prevailed at the time of the incident.

The captain of the flight stated that he had disengaged the autopilot (A/P) approximately 15 miles from the airport and was flying a manual approach. No problems were observed with the rudder or yaw damper during this time. However, when the captain attempted to use the rudder to compensate for a crosswind just before landing, he discovered that the rudder pedals were "locked in the neutral position." The captain used aileron inputs to keep the airplane aligned with the runway centerline through the touchdown and differential braking to steer the airplane during the landing roll until he engaged nosewheel steering at 80 knots. After exiting the runway, the captain performed several A/P disconnects, with no change in the rudder pedal force. He and the first officer then made several attempts to free the rudder pedals. After manipulating the rudder for approximately 15 seconds, the rudder pedal movement returned to normal.

Following the incident, NWA maintenance personnel examined the rudder and A/P systems. No anomalies were observed and no evidence of water or ice was found on the rudder cable assemblies. The rudder A/P artificial feel and trim solenoid was removed and replaced, and the airplane was returned to service the day after the incident. Subsequent Safety Board analysis of the flight data recorder readout confirmed that the A/P was disengaged when the captain experienced stiff rudder pedals.

At the request of the Safety Board, the rudder artificial feel and trim unit from the airplane was tested at an Airbus laboratory under supervision of the French Bureau Enquete Accidents. Although the unit's solenoid functioned properly, excessive forces were required to rotate the unit's A/P-mode engagement/disengagement lever. This occurred during testing at ambient and cold temperatures (-40° F).

A review of the service history on the A-320 rudder system revealed Airbus Service Bulletin (SB) A320-27-1042, dated March 21, 1992, titled "Flight Controls - Rudder - Increase Radial Play of Lever Bearing in the Artificial Feel and Trim Unit." The SB was prompted by 10 incidents in which the artificial feel and trim unit did not disengage from the A/P mode (stiff pedal operation) and return to normal pedal operating forces during approach and landing. These failures were attributed to increased operating forces in the bearing of the A/P engagement/disengagement lever in the artificial feel and trim unit and may have been aggravated by exposure to cold temperatures. The SB introduced a modified lever with a larger radial play of the bearing to eliminate the problem. On April 30, 1997, Airbus sent a telex to A-320 operators citing two recent incidents involving stiff rudder pedals and strongly recommending that the SB action be incorporated. The Direction Generale De L'Aviation Civile, the French aviation authority, has not issued an airworthiness directive (AD) to require the SB modification (which is not mandatory).

The NWA A-320 involved in the November 24, 1996, incident had not been modified in accordance with the SB. Because an unexpected restriction of the rudder pedals could cause a loss of control during a critical phase of flight, the Safety Board believes that the Federal Aviation Administration should issue an AD to require the installation of a modified engagement/disengagement lever in the rudder artificial feel and trim unit on all Airbus A-320 airplanes, in accordance with Airbus SB A320-27-1042, to ensure that the correct operating force exists at the rudder pedals. Although the SB modification has been incorporated on most of the A-320 airplanes operating in the United States, America West has indicated that some of its airplanes have probably not been modified. Full fleet compliance is necessary to ensure that none of the remaining airplanes are affected by this known system problem. The Safety Board is also concerned that A-320 airplanes could enter into U.S. service in the future without the SB modification.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Issue an airworthiness directive to require the installation of a modified engagement/disengagement lever in the rudder artificial feel and trim unit on all Airbus A-320 airplanes, in accordance with Airbus Service Bulletin A320-27-1042, to ensure that the correct operating force exists at the rudder pedals. (A-98-24)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 25, 1998
In reply to refer to: A-98-25 and -26

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On January 26, 1997, Northwest Airlines (NWA) flight 20, a Boeing 747-251, N627US, experienced an engine case rupture of its No. 1 Pratt & Whitney (P&W) JT9D-7Q engine during takeoff at Narita International Airport, Tokyo, Japan. During the takeoff roll, as engine power was set to approximately 1.58 engine pressure ratio and the airplane was rolling forward at low speed, a loud bang was heard by the flightcrew. The captain rejected the takeoff and returned to the gate without further incident; no injuries resulted. The crew reported that there were no fire warning or nacelle overheat indications. The airplane was operated under Title 14 Code of Federal Regulations Part 121, as a regularly scheduled passenger flight from Tokyo, Japan, to Minneapolis, Minnesota.

The No. 1 engine diffuser case ruptured and as a result, both engine side cowl doors, a precooler, and other hardware were ejected from the engine. The escaping gas and engine debris blew out the engine pylon access panels, and created holes, cracks, and other damage to the wing's leading edge, aileron, and flaps. Engine debris came to rest on the only runway at the airport, causing the airport to be closed for several hours.

The National Transportation Safety Board's (NTSB) examination of the engine discovered an L-shaped crack in the outer pressure wall in the rear skirt area of the diffuser case that was deflected outward exposing the bulged combustion chamber inside the engine. The crack extended fore and aft approximately 18 inches from the diffuser case's rear flange at the 11 o'clock[1] position. The crack turned 90° and extended circumferentially around approximately 120° of the case's circumference, in the counterclockwise direction. The crack passed adjacent to a 3-inch long, dog bone-shaped embossment (boss), located about 10 inches forward of the rear flange at the 11 o'clock position. The boss was the attachment point for the upper most mount bracket of the engine's 116-pound precooler.[2]

[1] All references to the clock are as viewed from aft looking forward.
[2] The precooler is an air-to-air heat exchanger that cools the engine bleed air from the high-pressure compressor (HPC) with cooler fan discharge (ram) air. Pressurized air from the HPC is regulated by 8th- and 15th-stage bleed air valves before entering the precooler. Ram air is regulated by two valves as it exits the precooler.

A section of the diffuser case rear skirt (see figure 1) was examined at the Safety Board's materials laboratory in Washington, D.C. Examination of the fracture surface, approximately 10 ½ inches from the rear flange, adjacent to the upper precooler mount boss, revealed a 5-inch long discolored high cycle fatigue[3] (HCF) zone with about 90,000 striations. The fatigue initiated at a crack that looked like two thumbnail-shaped, gray-colored areas, which were approximately 0.040-inch wide by 0.010-inch deep. High levels of delta phase precipitate[4] were discovered in the thumbnail-shaped origin areas. Individual 0.0005 to 0.0008-inch deep toolmarks or scratches were found on the outer case wall extending the length of the origin area. Numerous additional toolmarks were found on the exterior surface of the rear skirt. The toolmarks were formed when the exterior surface of the case was machined (blended) during manufacture. The diffuser case had accumulated 9,342 total flight cycles[5] since new.

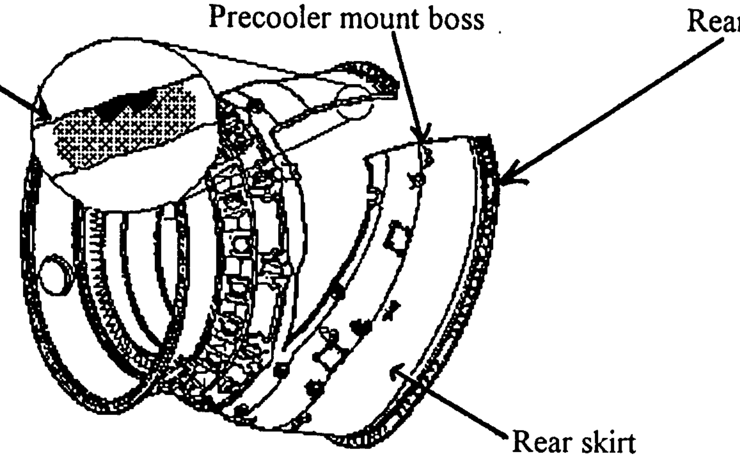

Figure 1: Ruptured diffuser case

A metallurgical analysis of the fracture surface indicated that the thumbnail-shaped cracks had initiated at the base of the toolmarks because of a combination of high residual stresses and low-cycle fatigue[6] (LCF). The crack then propagated in HCF, as evidenced by the very small striation spacing found in the majority of the 5-inch long fatigue zone, after which the crack progressed to failure in tensile overload.

Based on the morphology of the fracture, metallurgical tests were also conducted at P&W's Mechanics and Material Engineering laboratory, in East Hartford, Connecticut, to evaluate the case material's fatigue properties that were initiated by toolmarks. Specimens tested with toolmarks present were found to have one-fourth the predicted life of identical specimens tested without toolmarks.

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[3] HCF is a phenomenon in which a crack progresses an incremental amount (one striation) as a result of the cyclical stresses associated with vibration.

[4] The delta phase precipitate is a normally existing high temperature phase in INCONEL 718 and was most likely formed by the elevated temperatures associated with the heat treatment process of the diffuser case.

[5] A flight cycle is one takeoff and landing.

[6] LCF is a phenomenon in which a crack progresses an incremental amount (one striation) as a result of the cyclical stresses associated with rise and fall of the engine's internal pressure, temperature, or the revolutions per minute associated with each flight cycle.

Metallurgical examination of the precooler at the Safety Board's materials laboratory revealed HCF cracks at the attach points of two internal support rods. Seven other rods with identical HCF cracks were found to have been previously weld repaired. Wear marks and contact marks were also found on the engine bracket and support link of the precooler's upper attachment point. Additionally, a review of the maintenance records revealed that seven flight cycles before the diffuser case rupture, the engine had an in-flight shutdown (IFSD) because of a turbine cooling air (TCA) tube failure. The records revealed that during the inspection following the IFSD, the TCA tube mount clamp, which normally supports the tube at about mid-span, was discovered missing, and a station-4 static pressure sense line (Ps4) was also discovered to be fractured. The TCA tube and clamp, and the Ps4 line were replaced. The records also revealed that 260 flight cycles before the diffuser case rupture, a cracked lenticular seal[7] was discovered during disassembly of the high-pressure turbine.

The incident aircraft had no engine vibration monitoring (EVM) equipment. Although no EVM equipment was installed, the fractured diffuser case and Ps4 line, the missing TCA tube, the precooler cracks, and the precooler bracket wear suggest a vibratory environment. As a result, the Safety Board's investigation attempted to identify potentially vibratory resonant conditions or excitation sources within the engine. A vibration survey was performed at P&W on a normally operating JT9D-7R4 engine that had a similar diffuser case but no precooler. P&W also conducted finite element analyses of the JT9D-7Q's TCA tube installation and the precooler installation to determine the stresses from an assumed engine oscillatory force equivalent to 2.5 times the force of gravity, which is considered to be a high vibration level for this engine. Finally, P&W estimated the amount of vibratory excitation imparted to the engine because of a cracked lenticular seal.

The results of the vibration survey did not reveal any resonant conditions or excitation sources stemming from normal engine operation. The finite element analysis of the precooler installation revealed that the stresses from a high vibrating engine were not sufficient to initiate a crack in the case. Finally, the maximum levels of vibration from a cracked lenticular seal, or from a supported or unsupported resonating TCA tube, were not of sufficient magnitude to be excitation sources.

A review of the failure history of the JT9D-7Q since certification in 1978, revealed that this is the first diffuser case rupture originating in the rear skirt area. The JT9D-59A and -70, which have an interchangeable diffuser case with the JT9D-7Q, had two diffuser case rupture events early in their operation history; these originated in the front skirt area. Since the issuance of Airworthiness Directive 94-26-06, which requires inspection of the front skirt in the vicinity of the 15th-stage bleed air bosses, no additional ruptures have originated in the front skirt area.

The proximity of the crack origin to the precooler mount boss and the HCF crack propagation suggests that high precooler vibration imparted higher than normal loading into the precooler mount boss and the diffuser case. Additionally, the postincident fatigue tests of the case material indicates that high levels of vibration alone are insufficient to initiate a crack. The

[7] The lenticular seal is a torroid-shaped, steel seal clamped between the 1st-and 2nd-stage HPT disks that incorporates four knife edge seals around the outer diameter.

evidence also suggests that a tool mark or other defect in the case, combined with LCF, is required to initiate a crack and that high levels of vibration can propagate the crack.

As a result, P&W reports that it is drafting a service bulletin to propose a repair for toolmarks stemming from the blending of the diffuser case during manufacture. Additionally, Boeing reports that it is drafting a service letter that proposes a rework of the engine bracket to the precooler's upper attachment point on the JT9D-7Q installation to increase clearance between the bracket and support link to reduce vibration and to reduce wear.

Because it appears that preventative measures can obviate future diffuser case ruptures originating in the rear skirt area with minimal impact to airline operations, the Safety Board believes that the Federal Aviation Administration (FAA) should require a one-time visual inspection of the diffuser case rear skirt on P&W JT9D-7Q engines to locate scratches and tool marks when the diffuser case is next at the piece-part level, and blend repair as required to prevent tool marks and scratches from becoming crack initiation sites. The Safety Board also believes that the FAA should require modification of the engine bracket that attaches to the diffuser case's precooler upper mount boss on the P&W JT9D-7Q installation to increase clearance between the bracket and support link to reduce vibration and to reduce wear.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require a one-time visual inspection of the diffuser case rear skirt on Pratt & Whitney JT9D-7Q engines to locate scratches and tool marks when the diffuser case is next at the piece-part level, and blend repair as required to prevent tool marks and scratches from becoming crack initiation sites. (A-98-25)
>
> Require modification of the engine bracket that attaches to the diffuser case's precooler upper mount boss on the Pratt & Whitney JT9D-7Q installation to increase clearance between the bracket and support link to reduce vibration and to reduce wear. (A-98-26)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

CORRECTED COPY

Date: March 6, 1998

In reply to refer to: A-98-27 through -33

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On September 7, 1997, Canadian Airlines International flight CP30, a Boeing 767-300ER airplane, equipped with General Electric Aircraft Engines (GEAE) CF6-80C2B6F engines, experienced an uncontained failure[1] of the high-pressure compressor (HPC) stage 3-9 spool (figure 1) in the No. 1 (left) engine during takeoff at Beijing, China. The airplane was on a regularly scheduled passenger flight from Beijing to Vancouver, Canada. The flightcrew reported that during the initial part of the takeoff as the throttles were advanced, the No. 1 engine surged. This was followed by a fire warning in the cockpit and significant vibration in the airplane. The crew rejected the takeoff at a speed of about 20 knots and discharged both fire bottles for the No. 1 engine. The engines were shut down, and the airplane was towed to the terminal without further incident. The 199 passengers and 10 crewmembers on board sustained no injuries.

The examination of the engine revealed substantial damage in the area of the HPC. The HPC case was ruptured aft of the stage 2 variable stator vanes. The stage 3 disk portion of the HPC stage 3-9 spool had separated from the remainder of the spool, exited the engine, and broken into three pieces, all of which were recovered. The No. 1 engine's right-hand thrust reverser cowl had a 2-inch by 1-inch cut in the skin. The reported fire was caused by fuel that had leaked from a line that supplies pressure to the active clearance control[2] valve, which was severed by one of the liberated pieces of the 3rd-stage disk.

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[1] An uncontained engine failure occurs when an internal part of the engine fails and is ejected through the cowling.

[2] The active clearance control system provides air to externally cool the turbine cases to minimize the thermal growth of the cases that reduces the gaspath leakage between the turbine blade tips and turbine case air seals to improve an engine's fuel efficiency.

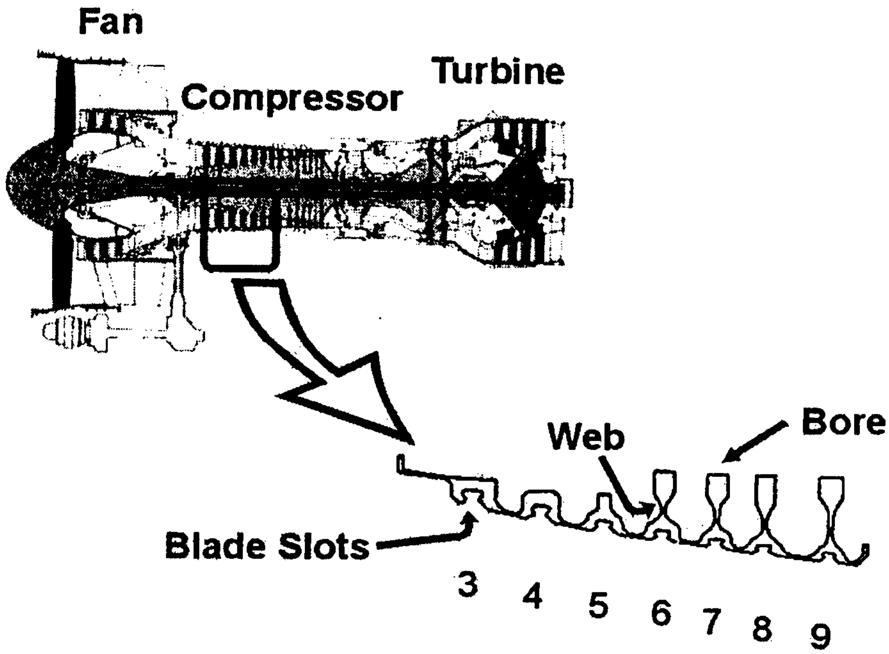

Figure 1.—Typical 3-9 spool in cross section.

The investigation of this incident is under the direction of the Transportation Safety Board of Canada (TSB). The National Transportation Safety Board, under the provisions of Annex 13 to the International Convention on Civil Aviation, is assisting the TSB with its investigation. Information gathered in the investigation thus far raises serious concerns that warrant action by the Federal Aviation Administration (FAA).

The HPC stage 3-9 spool is a rotor component that is composed of disks joined together with integral spacer segments and end flanges and is made from Ti-6242 titanium alloy.[3] The incident spool, part number 1333M66G01, was a two-piece assembly made by GEAE in 1989.[4] According to maintenance records, the spool had accumulated a total of 25,653 hours and 4,744 cycles since new (CSN). The front portion of the spool was forged by Schlosser Forge Company

[3]Titanium-based alloy containing 6 percent aluminum, 2 percent tin, 4 percent zirconium, and 2 percent molybdenum.

[4]The stage 3-9 spool was first manufactured by GEAE in 1971 for the CF6-50 engine as a one-piece spool that was forged from a 16-inch diameter billet. (A billet is a semifinished round product from which a part is forged. The required diameter of a billet is achieved by hot-working [forging] of an ingot in several stages.) In 1980, the billet diameter was reduced to 13 inches to improve the inspectability and provide for more working of the material during forging. Also around 1980, GEAE began to produce two-piece spools from 12-inch and 13-inch diameter billets. In the two-piece configuration, the front (stages 3 through 5) and rear (stages 6 through 9) portions of the spool are forged separately. The forgings are then machined to a rectilinear shape (which has straight sides and perpendicular corners), welded together, heat treated, and machined to the final shape. Between 1988 and July 1995, GEAE produced two-piece spools that had the front and rear portions of the spool forged from 9-inch and 10-inch diameter billets, respectively. Until 1995, all two-piece spools received a postweld solution heat treatment followed by a slow cool down. In 1995, that process was replaced by a postweld stress-relief process. Also, in July 1995, GEAE started to produce two-piece spools forged from 8-inch diameter billets.

from a 9-inch diameter billet produced by Reactive Metals Incorporated (RMI), and the aft portion was forged by Wyman-Gordon Company from a 10-inch diameter billet produced by Titanium Metals Corporation of America. Both pieces were welded by GEAE, and machined to the final shape by Volvo Aero Corporation, Trollhattan, Sweden.

Metallurgical examination of the 3rd-stage disk of flight CP30's HPC spool was conducted at the TSB's engineering and the Safety Board's materials laboratories. The examination revealed a fatigue fracture that was about 1 ¾-inches long and about ½-inch deep, emanating from an area (not a clear, specific origin) at or near the bottom of a dovetail blade slot. Metallographic examination of numerous sections from the area of the fracture revealed a band of abnormal microstructure that contained predominantly alpha phase (the Ti-6242 alloy outside of the area of abnormal microstructure contained a mixture of approximately equal amounts of alpha and beta phases[5]) and elevated oxygen levels. This band of abnormal microstructure extended from the front to the rear face of the 3rd-stage disk and intersected the bottom of the dovetail slot.

Microprobe and wavelength dispersive analysis of several locations along the band of abnormal microstructure revealed oxygen levels of 0.4 to 0.6 percent. The applicable GEAE specification for Ti-6242 titanium alloy, C50TF39-S4, restricts oxygen content to a maximum of 0.15 percent. A spectrographic chemical analysis of the 3rd-stage disk material away from the fracture area and well outside the band of abnormal microstructure showed that it conformed to the GEAE specification requirements for Ti-6242 alloy. Hardness tests showed that the maximum hardness in the oxygen-rich area was 43 on the Hardness Rockwell C scale (HRC). In comparison, the hardness in other areas of the spool ranged from 29 HRC to 40 HRC (averaging 35 HRC), which, according to GEAE, is typical for premium quality Ti-6242 alloy.[6]

Further, the examination of the fracture surface with a scanning electron microscope revealed that about 80 percent of the fatigue region contained brittle cleavage-like,[7] faceted features with no identifiable fatigue striations, and about 20 percent contained classical fatigue striations. Metallurgists were able to count about 800 classical fatigue striations along a radial line extending through the fatigue region from the dovetail slot bottom to the stage 3 disk bore.

Adequacy of Current In-Service Inspection Techniques for Detecting Cracks

The records for the incident engine show that in October 1994, the engine, including the HPC stage 3-9 spool, was overhauled because of the ingestion of recapped tire fragments into the engine during the takeoff roll. The overhaul was performed by Caledonian Airmotive,[8] Prestwick, Scotland, at 2,758 CSN (1,986 cycles before the incident) and included a fluorescent penetrant

[5]When titanium takes the crystallographic form known as "alpha phase" (also referred to as a low-temperature titanium phase) it has a hexagonal close-packed crystal structure. When it takes the crystallographic form known as "beta phase" (also referred to as a high-temperature titanium phase) it has a body-centered cubic crystal structure.

[6]Applicable GEAE material specification C50TF39-S4 does not specify a required minimum or maximum hardness level for Ti-6242.

[7]Cleavage refers to the splitting of a crystallized substance along definite crystal planes.

[8]Caledonian Airmotive was subsequently acquired by Greenwich Aviall, and then by GE Caledonian.

inspection (FPI)[9] and an ultrasonic[10] inspection. The maintenance records show that neither the FPI nor the ultrasonic inspection revealed any rejectable indications in the spool.[11]

The investigation revealed that the FPI and ultrasonic inspection techniques performed on the spool in 1994, even when combined with the eddy current inspections,[12] which were subsequently included in the GEAE engine maintenance manual for the inspections of HPC stage 3-9 spools, do not provide 100 percent inspection coverage of the spool. According to GEAE, the currently prescribed manner in which the ultrasonic inspection probe is directed at the spool's disk bore results in several internal "blind spots" that are beyond the coverage capabilities of the ultrasonic inspection technique. The crack that resulted in the uncontained failure of flight CP30's HPC stage 3-9 spool originated from an area located in one of these blind spots. The investigation determined that by repositioning the ultrasonic probe to the dovetail slot, this area could be fully inspected. However, it is uncertain whether, even if the probe had been repositioned, a detectable crack existed in the incident spool at the time of the 1994 inspections.

The Safety Board concludes that because the currently prescribed in-service inspection techniques do not provide 100 percent inspection coverage of the HPC stage 3-9 spool, these inspections do not ensure the detection of all cracks. Although improved inspection coverage might not have affected the outcome of this incident, the Safety Board is nonetheless concerned that the inspection techniques currently in use permit blind spots in the area of the dovetail blade slots, which are high-stress areas of the spool. Therefore, the Safety Board believes that the FAA should require GEAE to develop and implement improved inspection techniques that will provide 100 percent inspection coverage of high-stress areas of the CF6-50 and -80 series HPC stage 3-9 spool and that will provide the maximum coverage possible of other areas. The Safety Board is also concerned that the incomplete inspection coverage of multistage compressor spools may not be limited only to GEAE CF6-50 and -80 series HPC stage 3-9 spools, but may exist for other multistage compressor spools. Therefore, the Safety Board believes that the FAA should review the prescribed nondestructive inspection techniques for all turbine engine multistage titanium compressor spools to ensure 100 percent inspection coverage of high-stress areas and maximum coverage possible for all other areas and, if necessary, require engine manufacturers to develop and implement improved inspection techniques.

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[9]During FPI, a dye is applied to the surface of the part. The dye penetrates cracks and leaves a surface indication detectable with fluorescent light.

[10]Ultrasonic inspection is a nondestructive method in which beams of high-frequency sound waves are introduced into materials to detect subsurface flaws in the material.

[11]GEAE, Air Accident Investigation Branch of the United Kingdom, and Safety Board personnel reviewed the strip charts from the ultrasonic inspection and confirmed that there were no indications requiring any action. (A strip chart is a continuous length of graph paper that is used to record data in relation to time or distance.)

[12]Eddy current inspections measure fluctuations in an alternating magnetic field around a part generated by a transducer carrying an alternating current. The inspection is used to locate surface and near-surface defects. Eddy current inspections of the HPC stage 3-9 spool were not performed in 1994, when the incident engine and spool were last overhauled.

Possible Role of Melt Deviations in Creating Abnormal Microstructure

The investigation has not formally determined the cause of the abnormal microstructure in the incident spool. However, investigators are examining the possibility that it was related to deviations in the melt process that allowed the introduction of oxygen into the melt. The manufacturing records of the ruptured HPC stage 3-9 spool from flight CP30 indicate that the forward section of the spool (stages 3 through 5) was produced by RMI from Heat[13] No. 981897. RMI's manufacturing records for that heat indicate that the titanium electrode[14] shifted position within the crucible[15] during the second melt. The manufacturing records also indicate that about the same time as the electrode's shift in position, the pressure inside the crucible increased from the normal vacuum of about 100 microns of atmospheric pressure to 900 microns of atmospheric pressure.[16] This increase occurred over the space of 1 minute. Approximately 30 minutes later, the pressure had returned to the normal vacuum of about 100 microns of atmospheric pressure. According to RMI, it is likely that the increase in pressure resulted from the electrode's shift in position, which could have allowed the cooling water from the jacket that surrounds the crucible to leak into the melt. Although the extent of the pressure change (known as a "vacuum excursion") was within RMI and GEAE specifications, which permitted pressure deviations of up to 1,000 microns during the second melt, RMI notified GEAE of the vacuum excursion.[17] GEAE accepted the melt. Subsequently, in October 1991, RMI reduced the specifications for permissible vacuum excursions during secondary and final melts to 750 microns.

A review of GEAE manufacturing records showed that 21 HPC stage 3-9 spools, in addition to the flight CP30 spool, were manufactured from RMI Heat No. 981897.[18] On October 31, 1997, the FAA issued Airworthiness Directive (AD) 97-22-14, which required the removal from service of all 21 spools within 30 days. The FAA and GEAE have advised the Safety Board that all of the other HPC stage 3-9 spools that had been manufactured from RMI Heat No. 981897 have been removed from service. According to GEAE, one of those spools has

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[13]A heat, or ingot, is a mass of metal melted into a convenient shape for handling that is later finished by rolling, forging, or other means.

[14]Titanium electrodes for the first (primary) melt consist of cold-pressed compacts containing a mixture of titanium sponge and elemental alloying materials that are welded together into an approximately 15-foot long, 18-inch diameter cylinder. The electrode in the second (intermediate) melt is produced by welding together two or three primary melt ingots end to end. The electrode in the third melt is the melted together mass from the second melt.

[15]The crucible is a water-cooled copper vessel in which the titanium electrode is melted.

[16]An absolute vacuum is zero microns. A standard day pressure of 29.92 inches of mercury is equivalent to 9,875,118 microns.

[17]According to RMI, it notified GEAE of the vacuum excursion because it was close to the maximum excursion allowable (within 100 microns) and its time span was unusually long (approximately 30 minutes).

[18]Of these, only one spool was installed in a U.S.-registered airplane, a Continental Airlines DC-10, N87071. This spool had accumulated 1,075 CSN, far less than the 4,744 cycles that had been accumulated on the spool from flight CP30.

received an ultrasonic, eddy current, and blue-etch anodize (BEA) inspection,[19] and there were no indications of defects or cracks.[20]

According to GEAE, there have been 10 uncontained HPC stage 3-9 spool failures in CF6-50 and -80 series engines.[21] GEAE further indicated that two of these failures, occurring in 1974 and 1979, were caused by fatigue fractures originating from oxygen-rich inclusions in the spools. These spools, which were produced from 16-inch diameter billets melted by RMI, had reportedly accumulated 483 and 2,854 CSN, respectively, at the time of the failures. In a December 5, 1997, letter to the TSB, RMI stated that the furnace records for the two heats from which these spools had been produced showed that minor vacuum excursions had occurred during the initial melt but that those excursions were typical for the production process that was in use and well within RMI and GEAE specification limits. Records also show that one of the heats had an excursion of 600 microns in the second melt (which was within the then-current limits and is within the revised limits for secondary melts).

The Safety Board is concerned that additional HPC stage 3-9 spools or other critical components manufactured from ingots that contain melt variations that can result in abnormal microstructure may be currently in service. Therefore, the Safety Board believes that the FAA should review GEAE's Ti-6242 titanium alloy suppliers' melting records and identify any vacuum excursions or other process deviations that exceed current specifications or that may otherwise cause an inclusion or abnormal microstructure. The Safety Board also believes that based on the results of this review, the FAA should issue an AD to require removal from service and/or inspections of the components manufactured from these melts.

Rapid Propagation of the Crack and the Possible Role of Dwell Time Fatigue

As mentioned above, the fracture morphology of the incident spool was atypical in that most of the fracture region contained brittle cleavage-like, faceted features, rather than classical fatigue striations. Further, the areas of classical fatigue striations included evidence of only 800 flight cycles, indicating a very rapid crack propagation. This fracture morphology is similar to that

[19]In 1991, GEAE began performing BEA inspections on the surface of newly manufactured spools as a further measure to prevent spools with microstructural anomalies from being put into service. However, within areas of generally abnormal microstructure, the arrangement of alpha and beta grains may be such that a given cross-section of the material may not indicate an abnormality that would be apparent from a different view. Therefore, although it is possible that a BEA inspection could detect an area of abnormal microstructure such as that in the incident spool, it is also possible that the microstructure at the surface might not exhibit an abnormal appearance and thus would not be detected by a BEA inspection.

[20]The AD did not require that the spools be subjected to testing after being removed from service.

[21]The Safety Board has previously expressed concern about the continued airworthiness of GEAE CF6-50 and -80 series engine HPC stage 3-9 spools. In 1995, the Safety Board assisted the Egyptian Civil Aviation Authority with the investigation of an uncontained failure of a GEAE CF6-50 HPC stage 3-9 spool that occurred on an Egypt Air Airbus A300B4 during takeoff at Cairo, Egypt, on April 10, 1995. The failure of that spool was caused by a fatigue crack that initiated from a nitrogen-stabilized hard-alpha inclusion in the web portion of the stage 6 disk.

exhibited in several earlier fractures of CF6-50 and -80 series 3-9 spools[22] that were attributed to a cracking phenomenon that became known as dwell time fatigue (DTF). (The Safety Board first became aware of DTF in 1995 during the investigation of the uncontained failure of the CF6-50 stage 3-9 spool that occurred on the Egypt Air Airbus A300.)

DTF refers to a fracture mechanism in which progressive crack growth occurs during cyclic loading (rise and fall of stress) and also over time during sustained peak-stress loading (during the dwell time at the peak stress level), both at low temperature. The fracture morphology is characterized by subsurface initiation and brittle, faceted-cleavage fracture features. According to GEAE, the DTF phenomenon is related to increased plastic strain and slip along crystallographically aligned alpha colonies[23] in the material microstructure. According to metallurgical research literature, the faceted fracture features that occur during DTF in alpha-beta titanium alloys are associated with large primary alpha colonies possessing a similar crystallographic orientation.[24] Other literature indicates that DTF develops at high stresses (approaching the yield stress of the material) and is associated with hydrogen embrittlement developed during time-dependent plastic deformation at the dwell stress.[25]

GEAE conducted a test program[26] that indicated that a significant reduction in a material's fatigue life occurs when it is subject to DTF as compared to conventional fatigue cycling. However, GEAE has been unable to determine the time it takes from manufacture until a crack initiates or the propagation rate of a crack once it initiates in DTF. Absent a predictable crack initiation time and propagation rate (which can be used to establish required inspection intervals designed to detect cracks before they propagate to failure), the prior failure history of the component provides the only data on which to base inspection intervals.

On August 25, 1995, as a result of a review of the spool failures associated with the DTF phenomenon, the Safety Board issued Safety Recommendation A-95-85 urging the FAA to revise AD 95-03-01 (applicable to GEAE CF6-50, -80A, and -80C2 model engines) to require repeated inspection of all HPC stage 3-9 spools that had been solution heat treated after welding.[27] The

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[22]Of the 10 aforementioned uncontained HPC stage 3-9 spool failures, GEAE attributed 4 of the failures to the DTF fracture mechanism. [(a) the 1985 failure in Dakar, Senegal, of a CF6-50, stage 9 disk with 4,075 CSN, which was part of a one-piece spool; (b) the 1991 failure in Seoul, Korea, of a CF6-50, stage 9 disk with 10,564 CSN, which was part of a one-piece spool; (c) the 1993 failure in Los Angeles, California, of a CF6-80C2 stage 6 disk with 4,403 CSN, which was part of a one-piece spool; and (d) the 1995 failure in Bangkok, Thailand, of a CF6-50 stage 8 disk with 8,438 CSN, which was part of a one-piece spool.]

[23]Crystallographically aligned alpha colonies are areas of the microstructure in which a group of alpha grains in proximity to one another have their crystallographic planes similarly oriented.

[24]Woodfield, A.P. et. al. 1995. "Effect of Microstructure on Dwell Fatigue Behavior of Ti-6242." *Titanium '95: Science and Technology*. p. 1116-1123.

[25]Hack, J. E.; Leverant, G. R. 1982. "The Influence of Microstructure on the Susceptibility of Titanium Alloys to Internal Hydrogen Embrittlement." *Metallurgical Transactions*, Volume 13A. p. 1729–1738.

[26] The results of this test program are documented in "Effect of Microstructure on Dwell Fatigue Behavior of Ti-6242," published in *Titanium '95: Science and Technology*. (See complete citation in footnote 24, above).

[27]Until 1995, all two-piece spools received a postweld solution heat treatment followed by a slow cool down. In 1995, according to GEAE, it replaced the solution heat treatment process with a postweld stress-relief process to

Safety Board urged that the maximum interval between inspections should be appropriately less than the 4,000 cycles specified in that AD.[28]

The FAA responded that it agreed with the safety recommendation to require inspections of most GEAE CF6-50, -80A, and -80C2 HPC stage 3-9 spools but did not agree that there should be a maximum interval between all inspections. On November 13, 1995, the FAA issued AD 95-23-03, superseding AD 95-03-01, which reduced the repetitive inspection interval requirements for one-piece HPC stage 3-9 spools made from 16-inch diameter billets used in GEAE CF6-50, -80A and -80C2 engines from a maximum of 4,000 cycles to a maximum of 3,500 cycles. A 3,500-cycle inspection interval was also established for spools made from 13-inch diameter billets that are used on GEAE CF6-80C2 engines. However, the FAA did not make any requirements for mandatory repetitive inspections for one-piece HPC spools made from 13-inch diameter billets installed in CF6-80A engines or on any spools made from two-piece forgings.

In its April 16, 1996, response to the FAA, the Safety Board expressed its concern that further failures of stage 3-9 spools could occur at the 3,500-cycle inspection interval and stated that it believes the 3,500-cycle inspection interval was based primarily on economic considerations, not on fracture propagation or low-cycle failure events. The Safety Board response further stated that the earliest DTF separation of a compressor spool had occurred after 4,075 CSN in a spool made from a 16-inch diameter billet. The Safety Board also investigated the separation of an HPC spool made from a 13-inch diameter billet that occurred in a CF6-80C2 engine after 4,403 CSN. The pieces of the separated spool containing the fracture origin area were not recovered, so the exact fracture mechanism was not determined. However, the investigation concluded that the aligned alpha colonies in the microstructure of the spool made it susceptible to DTF. These spool separations indicate that complete failure resulting from DTF can occur after a relatively low number of cycles.

In a December 3, 1996, letter, the Safety Board indicated that AD 95-23-03 did not satisfy the intent of Safety Recommendation A-95-85, and the recommendation was classified "Closed—Unacceptable Action."

The Safety Board notes that in addition to having a fracture morphology similar to that of the spools that failed from DTF, the fracture of the stage 3 disk on flight CP30 initiated at a subsurface location in an area of high stress, and the material microstructure contained an aberrant alpha structure. Although the fracture initiation area of the flight CP30 spool did not exhibit crystallographically aligned alpha grains, such as has been associated with previous DTF fractures, it did contain an area of predominately alpha phase. In contrast, the fracture mechanism on the spool of the Egypt Air Airbus A-300 that failed in 1995, which was also made from Ti-6242,

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eliminate what GEAE had determined to be a propensity for grain growth and crystallographically aligned alpha colonies that occurred during the slow cool down from high temperature.

[28]AD 95-03-01, issued on February 16, 1995, required repetitive (at intervals not to exceed 4,000 cycles) ultrasonic and eddy current inspections of spools made from 16-inch diameter billets. (AD 91-20-01, issued October 25, 1991, had earlier required one-time [within 3,500 cycles] ultrasonic and eddy current inspections of spools made from 16-inch diameter billets.)

showed classical fatigue striations that correlated by striation count to the total engine cycles for the spool (indicating much slower propagation rates than those produced by DTF). Further, the fracture features on the Egypt Air spool did not contain cleavage-like, faceted fractures like those associated with DTF, nor did the microstructure contain any aberrant alpha phase. This shows that not all fatigue failures of the Ti-6242 alloy exhibit this unusual fracture morphology and those that do have aberrant alpha phase in the microstructure.

This suggests that although stage 3-9 spools made from Ti-6242 that have a normal, homogeneous alpha/beta microstructure can operate in service free of any cracking, if the spool has an abnormal alignment or distribution of alpha grains in a high-stress area, it can fracture unpredictably and rapidly. Although the Safety Board recognizes that failures associated with DTF and the failure of the 3-9 spool from flight CP30 might also have been affected by other as-yet-unknown factors, the Safety Board concludes that CF6-50 and -80 series HPC stage 3-9 spools may be uniquely susceptible to unpredictable crack-initiation times and rapid-crack growth rates. Therefore, the Safety Board believes that the FAA should conduct a critical design review of CF6-50 and -80 series HPC stage 3-9 spools to assess the overall safety and soundness of the part. The review should, at a minimum, evaluate the following: the adequacy of current and past manufacturing processes, including the ability of current and previous melt specifications and postweld procedures to protect against the creation of microstructural abnormalities; the propriety of using Ti-6242 titanium alloy, including the possible susceptibility of this alloy to the development of aberrant or undesirable crystallographic arrangements of alpha phase and a resulting vulnerability to rapid cracking; and the adequacy of the stress margins for the spool in the presence of an aberrant or undesirable microstructure.

Further, the Board remains concerned that not all CF6-50 and -80 series HPC stage 3-9 spools are required to be subjected to repeated inspections at intervals appropriately less than 4,000 cycles. Further, because it is not yet known (because the change is too recent) whether the cessation in 1995 of the postweld solution heat treatment has eliminated the susceptibility of those parts to DTF, it is possible that even those spools that were not subjected to this process are vulnerable. Therefore, the Safety Board believes that the FAA should revise AD 95-23-03, applicable to GEAE CF6-50, -80A, and -80C2 model engines, to include the -80E model engines, and to require repeated inspections of all HPC rotor stage 3-9 spools at maximum intervals appropriately less than 4,000 cycles.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require General Electric Aircraft Engines to develop and implement improved inspection techniques that will provide 100 percent inspection coverage of high-stress areas of the CF6-50 and -80 series high-pressure compressor stage 3-9 spool and that will provide the maximum coverage possible of other areas. (A-98-27)

> Review the prescribed nondestructive inspection techniques for all turbine engine multistage titanium compressor spools to ensure 100 percent inspection coverage of high-stress areas and maximum coverage possible for all other areas and, if

necessary, require engine manufacturers to develop and implement improved inspection techniques. (A-98-28)

Review General Electric Aircraft Engines' Ti-6242 titanium alloy suppliers' melting records and identify any vacuum excursions or other process deviations that exceed current specifications or that may otherwise cause an inclusion or abnormal microstructure. Based on the results of this review, issue an airworthiness directive to require removal from service and/or inspections of the components manufactured from these melts. (A-98-29)

Conduct a critical design review of CF6-50 and -80 series high-pressure compressor stage 3-9 spools to assess the overall safety and soundness of the part. The review should, at a minimum, evaluate the following:

- the adequacy of current and past manufacturing processes, including the ability of current and previous melt specifications and postweld procedures to protect against the creation of microstructural abnormalities; (A-98-30)

- the propriety of using Ti-6242 titanium alloy, including the possible susceptibility of this alloy to the development of aberrant or undesirable crystallographic arrangements of alpha phase and a resulting vulnerability to rapid cracking; (A-98-31) and

- the adequacy of the stress margins for the spool in the presence of an aberrant or undesirable microstructure. (A-98-32)

Revise Airworthiness Directive 95-23-03, applicable to General Electric Aircraft Engines CF6-50, -80A, and -80C2 model engines, to include the -80E model engines, and to require repeated inspections of all high-pressure compressor rotor stage 3-9 spools at maximum intervals appropriately less than 4,000 cycles. (A-98-33)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 7, 1998

In reply refer to: A-98-34 through -39

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On July 17, 1996, about 2031 eastern daylight time, a Boeing 747-131, N93119, operated as Trans World Airlines (TWA) flight 800, crashed into the Atlantic Ocean, about 8 miles south of East Moriches, New York, after taking off from John F. Kennedy International Airport, Jamaica, New York. All 230 people aboard the airplane were killed. The airplane, which was operated under Title 14 Code of Federal Regulations (CFR) Part 121, was bound for Charles De Gaulle International Airport, Paris, France. The flight data recorder and cockpit voice recorder ended simultaneously, about 12 minutes after takeoff. Evidence indicates that as the airplane was climbing near 13,800 feet mean sea level, an in-flight explosion occurred in the center wing fuel tank (CWT), which was nearly empty.

The source of ignition of the CWT has not been determined, and the investigation into a variety of potential ignition sources continues. However, the Safety Board's investigation has found damaged wiring in the fuel quantity indication systems (FQIS)[1, 2] of the accident airplane

[1] The B-747 FQIS measures fuel quantity with a capacitance measurement fuel probe system in each fuel tank. There are seven capacitance measurement fuel probes in the B-747 CWT. Each fuel probe consists of an inner tubular element that is surrounded by an outer tube. Compensators, located near the low point of each fuel tank, are also constructed of assemblies of tubular elements. The compensators and probes have a hard plastic terminal block near the top of each to provide for wiring connections. Wires from each fuel probe and the compensator are routed within the fuel tank through nylon clips to a connector located at the rear wing spar and are exposed to fuel and vapor.

[2] Most of the B-747-100, -200, and -300 series airplanes (about 700 airplanes) are equipped with FQIS manufactured by Honeywell Corporation; airplanes equipped with the Honeywell system are the subject of this letter. About 10 percent of the B-747-100, -200, and -300 series fleet has been retrofitted with FQIS manufactured by BFGoodrich Aerospace Corporation (formerly Simmonds Precision). The B-747-400 series airplanes are equipped with the BFGoodrich system equipment. No BFGoodrich FQIS were inspected during the investigation.

and three retired B-747s: N93105[3] and N93117[4] and a former Air France airplane, F-BPVE,[5] and the Safety Board was informed of damaged FQIS wiring in a British Airways B-747, G-BBPU.[6] These findings illustrate unsafe conditions that may exist in other B-747s and should be addressed by the Federal Aviation Administration (FAA).

The potential hazardous features found inside of B-747 fuel tanks during the investigation include the following:

1. FQIS wire insulation had been damaged near the attachment point of wires to four CWT fuel probe and compensator terminal blocks in N93105.[7] Terminal blocks with knurled (rough) areas on the surface had Honeywell Corporation manufacturing dates of November 1970[8] and earlier and were identified as Series 1, 2, and 3.[9] These terminal blocks had a metal strain relief clamp pressing the FQIS wires against the knurling. The knurled area consisted of a series of relatively sharp pointed cones in the hard plastic, and the edges of the terminal block castings transected the cones, thus creating sharp edges resembling saw teeth. The FQIS wire insulation had been cut by the knurled area, exposing the core conductors of some wires to the grounded shielding of others.[10]

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[3] N93105 had been undergoing maintenance when it was retired from service by TWA in 1994. The airplane had been in storage in Kansas City since that time.

[4] N93117 had been sold by TWA in 1992, and was subsequently placed in storage in Mojave, California, after 77,145 flight hours.

[5] F-BPVE was retired by Air France in September 1994. The airplane was subsequently used by the Safety Board and other agencies for testing in Bruntingthorpe, England.

[6] G-BBPU is an in-service B-747-136. At the time of its inspection on November 1, 1996, the airplane had been operated 89,639 hours and 17,437 cycles since new.

[7] Few terminal blocks from N93119 were recovered and most of those were fragmented or otherwise damaged. Although few of the fragments had attached FQIS wires, chemical traces on the exterior of damaged wire insulation had been deposited on and around previously damaged surfaces. Damage similar to that found in N93105 has been seen in some FQIS components from F-BPVE.

[8] On May 28, 1969, Boeing implemented a requirement for the wires to withstand a 50-pound pull, and on December 29, 1969, Honeywell Engineering Change Order 69 15826 revised the design to a Series 4 terminal block, which deleted the use of screws to fasten FQIS wires to the terminal block and introduced the use of threaded studs and nuts. On the Series 4 block, the metal strain relief clamp and knurling were deleted and the FQIS wires were held within the eye of a "P"-shaped nylon clamp that held the wiring above the terminal block surface. The change order was to be effective as soon as new terminal blocks were available. Boeing reported that a production change was made at Boeing that installed the Series 4 terminal blocks in [airplane] line number 65 and onward. Since N93119 was line number 153 and was delivered on October 27, 1971, Boeing concluded that it was improbable that it was delivered with Series 3 terminal block probes. A mixture of terminal block series that included Series 1-3 and subsequent designs were found in each of the cited B-747 airplanes, including N93119.

[9] The Honeywell Component Maintenance Manual still shows the Series 1-3 terminal blocks and metal strain relief clamps as "applicable" [acceptable] for use. Honeywell has reportedly supplied them as replacement parts, although only the updated design is now sold.

[10] Wire shielding covers the inner insulation and core conductor with a layer of woven wire, which isolates the conductor from electromagnetic signals and provides protection to the inner insulation and core conductor from external mechanical damage. Additional insulation covers the wire shielding.

2. In addition to the knurled surfaces found in the Series 1-3 fuel probes, B-747 fuel probe terminal blocks and compensators have squared edges that can damage wire insulation. A wire that had been located against the edge of a Series 1-3 terminal block from N93105 had a lengthwise cut in its insulation. (In contrast to the B-747 Series 1-3 terminal blocks, Honeywell also makes B-757 and B-767 fuel probes with terminal block edges that are smooth and rounded.)

3. The insulation of a fuel probe wire from the CWT in N93105 was also found to be displaced (cold-flowed), exposing its core conductor. The wire had been one of several pressed under the strain relief clamp of a Series 1-3 fuel probe terminal block. Wire insulation was also displaced by cold-flow or chafe at points of tight contact between wires not under the knurled clamps and where wires were pressed against plastic heat-shrink material on adjacent wires, in some instances exposing the conductor of one wire to the shield of a second wire. Displaced insulation that had been damaged but not breached was identified at various locations where wires pressed against other wires, where wires were in contact with the edge of a clamp, and at the edges of nylon clips where the FQIS wire routing made sharp turns inside the fuel tanks. Points of chafing and potential chafing were also found where FQIS wires contacted structure in the CWT of N93117.

4. During the accident investigation, two inappropriate repairs were found in the FQIS wiring in the wing tip fuel tanks of the accident airplane and another inappropriate repair was found by Boeing in a B-747 operated by another airline. The shielding of an N93119 wingtip tank FQIS probe wire had been previously broken and repaired. The repair of the wire consisted of splicing with a crimped connector and covering it with adhesive tape secured by wire bundle lacing tape.[11] Although the repair was functional, separated wire strands were found at the edge of the crimped connector. The separated strands had flat and angled-surface features, indicative of a fatigue failure. Boeing recommends that such broken FQIS wire be removed, solder-repaired, and covered with heat-shrink tubing. The second inappropriate repair found in N93119 was on a post-Series 3 compensator, where an oversized terminal block strain relief "P-clamp" had been used. The replacement P-clamp was larger than specified and unable to grip the FQIS wire harness. To provide strain relief, the wire harness had been looped to pass through the clamp twice and was still a loose fit. The third inappropriate repair was found in the CWT

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[11] Wiring in B-747s is assembled into harnesses with lacing tape made of Dacron, fiberglass, or Nomex, as specified in the Boeing Standard Wiring Practices Manual, section 20-00-11, page 17, Table XX, "Tie Materials."

of G-BBPU, where chafed FQIS wires had been repaired with fuel tank sealant.[12]

The damaged wiring at the terminal blocks was found only after the wiring had been removed. A close visual inspection in the tank without removing the wires would have been insufficient to disclose damage that is concealed between wires or under wire clamps. These types of damage could create spark gaps that are very small and that could become latent failures in the wiring system.

Boeing issued Service Bulletin (SB) 747-28-2205 on June 27, 1997, and a notice of status change for this SB on September 25, 1997, to address B-747 fuel tank inspection procedures. However, the recommended inspection procedures for FQIS wires, fuel probes, and compensators were not addressed in sufficient depth for operators to find wire insulation damage similar to that found during the TWA 800 accident investigation. Most of the damaged FQIS wire insulation found during the accident investigation was concealed beneath strain relief clamps or other wires and was discovered only after the wiring was removed from terminal blocks. In some cases, the damage was not apparent until the ends of the wires were inspected under magnification.

On October 27, 1997, Boeing issued a notice to B-747 operators (M-7220-97-1725) describing a planned SB that would provide further details on inspecting B-747 fuel probes, compensators, and FQIS wires. In an October 30, 1997, letter to the Safety Board, Boeing stated that the new SB will recommend the replacement of Series 1-3 fuel probes, the reporting of damage involving Series 4 and later fuel probes, the replacement of certain CWT FQIS wire harnesses, and the inspection for proper wire routing and existing damage; the SB will also establish an electrical resistance check of very low voltage and establish standards for FQIS repairs.

The Safety Board appreciates Boeing's efforts to develop a new SB to improve inspection of B-747 CWT FQIS components. However, compliance with SBs is not mandatory. The Safety Board believes that the FAA should issue, as soon as possible, an airworthiness directive (AD) to require a detailed inspection of FQIS wiring in B-747-100, -200, and -300 series airplane fuel tanks for damage, and the replacement or the repair of any wires found to be damaged. Wires on Honeywell Series 1-3 probes and compensators should be removed for examination.

In December 1969, Boeing reportedly discontinued using the Honeywell Corporation Series 1-3 fuel probes (with knurled terminal block surfaces and metal strain relief clamps) and began using the Series 4 (and later) fuel probes[13] as a product improvement. However, the change was not considered mandatory and Series 1-3 fuel probes are still found in airplanes. This investigation has shown that the knurling and the sharp edges of the early design terminal

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[12] The Boeing Standard Wiring Practices Manual describes methods and materials that can be used for wire repairs. It does not list fuel tank sealant as an approved material for repair of electrical wiring.

[13] See footnote 7.

blocks create damage to wire insulation. Changing to a Series 4 terminal block reduced the potential for FQIS wires to be damaged by the terminal blocks. However, the Honeywell overhaul manual still shows the Honeywell Series 1-3 terminal blocks as "applicable for use." The Safety Board believes that the FAA should issue an AD to require the earliest possible replacement of the Honeywell Corporation Series 1-3 terminal blocks used on B-747 fuel probes with terminal blocks that do not have knurled surfaces or sharp edges that may damage FQIS wiring.

Features of the fuel probes and wiring installation used in B-747s are similar to those of Honeywell fuel probes used in other airplanes, including the B-707, Lockheed C-130, B-757, and B-767. The B-707 and C-130 terminal blocks have a different shape but have some features similar to the B-747 design, including sharp edges. The B-757 and B-767 fuel probe terminal blocks have rounded edges and cast wire relief areas that are not used in the B-747 terminal blocks; the FQIS wires are retained in the cast wire relief areas by a flat metal bar. Wiring attached to the terminal blocks in airplanes other than the B-747 has not been examined by the Safety Board staff during the TWA 800 investigation. However, because of the similarities found during a review of fuel probe designs, the Safety Board is concerned that FQIS wiring problems discovered in this investigation may also exist in other airplanes with similar designs. Therefore, the Safety Board believes that the FAA should conduct a survey of FQIS probes and wires in B-747s equipped with systems other than Honeywell Series 1-3 probes and compensators and in other model airplanes that are used in 14 CFR Part 121 service to determine whether potential fuel tank ignition sources exist that are similar to those found in the B-747. The survey should include removing wires from fuel probes and examining the wires for damage. Repair or replacement procedures for any damaged wires that are found should be developed.[14]

Dark deposits were found around the wiring connections of fuel probes that had been removed from various fuel tanks in N93105, N93117, N93119, and F-BPVE. The deposits were found on wire insulation and on numerous plastic sleeves of crimped wire splices. A scanning electron microscope revealed that the dark deposits on N93119 and N93105 fuel probes contained copper, silver (silver-plated copper wiring is used in fuel tanks), and sulfur (a contaminant in jet fuel). The deposits on an N93119 FQIS compensator fragment were further examined at a U.S. Air Force research laboratory (Wright Laboratory) and were determined to be similar to copper sulfide deposits found in previous examinations of fuel probes from military aircraft. The laboratory had previously found that the deposits gradually reduced resistance between electrical connections of the military airplane fuel probes.

Wright Laboratory staff received a fuel probe that had been removed from a military trainer and tested at a maintenance depot while the probe was still wet with fuel. The test involved voltage and current levels greater than those that would be available from the FQIS. According to the Wright Laboratory staff, disassembly of the probe revealed soot and carbonized copper-sulfide deposits, apparently from the ignition of fuel vapors. A report by the Wright

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[14] Boeing is currently conducting a survey of Honeywell Series 4 probes and compensators.

Laboratory[15] states that a subsequent visual inspection found "discoloration and possible arcing on the bottom" of the probe. The report stated further, "It appears the internal probe wires were damaged by a fire. Evidence of an electrical arc was evident on the nylon cap which would have provided the required energy needed to ignite residual fuel." Another fuel probe documented by the same set of reports had evidence of an arc-track[16] with deposits composed of copper sulfide and carbon. Unburned deposits that were photographed by a scanning electron microscope had the appearance of flaking paint. Electronic testing for the resistance value of similar deposits on a third fuel probe revealed "small scintillating arcs" between the flakes, as current was increased to 5 milliamperes (voltage unknown) between a set of probes located 10 millimeters apart. When drops of JP-4 fuel were placed on the arcing deposit, the report said, "heat generated by the [electric] current rapidly evaporated the fuel. Resistance increased from 13,200 ohms to an open circuit (>20M)[17] after a few seconds." The flaking copper sulfide deposits were found to be a brittle substance that clung tenaciously to plastic materials and could only be cleaned by mechanical abrasion. The report concluded the following:

> The residues act as a thin film resistor that will rupture and open if significant current is passed through the material. Residue formation is most likely the result of a long-term degradation or corrosion process. Exposed silver plated copper wiring and other silver containing surfaces (electrodes) are apparently reacting with the sulfur in the fuel. This deterioration process is most likely time dependent and, as the probes age, more probe [calibration] failures can be expected.

Copper sulfide deposits were found inside the FQIS wire insulation of N93105 and N93119, where the wires had damaged insulation. The Safety Board is concerned that copper sulfide deposits on FQIS wires could become ignition sources in B-747 and similarly designed fuel tanks. The Safety Board believes that the FAA should require research into copper-sulfide deposits on FQIS parts in fuel tanks to determine the levels of deposits that may be hazardous, how to inspect and clean the deposits, and when to replace the components.

The investigation has also found that although the design for the B-747 CWT FQIS provides for limited electrical power in the fuel tank,[18] the FQIS wires are routed in bundles with nearly 400 other wires, some of which carry up to 350 volts.[19] The FQIS harness routed between

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15 Wright Laboratory Report "Analysis of Trainer Aircraft Fuel Probes I," dated March 1990, by George Slenski, Materials Integrity Branch, Systems Support Division, Materials Directorate.

16 Arc-tracking is an insulation failure leading to flashover. Tracks develop along the discharge path on the surface of the insulation. The tracks are generally more conductive than the virgin insulation. These tracks carbonize quickly into significant conducting paths.

17 Mega-ohms are one million ohms of electrical resistance.

18 Power to the FQIS is limited by Boeing to 0.02 millijoules, or less than 10 percent of minimum ignition energy (MIE) required to ignite Jet A fuel under laboratory conditions, according to the American Petroleum Institute Recommended Practice 2003, Fifth Edition, December 1991, entitled "Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents."

19 Zone A ceiling light wire W-1306-L1892-22 carries up to 350 volts. Numerous other wires carry 115 volts alternating current (VAC) and 28 volts direct current and are routed in bundles with FQIS system wires. Boeing

the CWT and the flight engineer's panel in the cockpit contains one shielded wire and two unshielded wires in a woven fiberglass sleeve. Boeing noted in an October 27, 1997, letter that this is a common design for capacitive FQIS systems. Behind the flight engineer's panel, the sleeved set of Teflon-insulated FQIS wires was connected to unprotected[20] general airplane wiring[21] that was routed to the fuel totalizer indicator and to the electrical/equipment (E/E) compartment located beneath the forward cabin and behind the nose landing gear. Additionally, unshielded Teflon wiring from the right wing fuel tanks was attached to a terminal strip located on spanwise beam No. 2 in the CWT, then was routed through the left wing fuel tanks to the ground refueling panel gauges located between the Nos. 1 and 2 engines. At the ground refueling panel, the fuel tank wiring was routed with other aircraft wiring for the refueling indicators and controls.

Electrical short circuits can introduce high voltage into low voltage conductors. For example, it was determined that a military C-130 fuel tank exploded in the 1970s after improper maintenance had created a short circuit within a fuel gauge electrical connector.[22] Maintenance work on the connector was not finished before the flight, and the investigation found that 115 VAC power was inadvertently allowed to enter the fuel tank through the shielding of FQIS wires.

In the investigation of a May 11, 1990, Philippine Airlines B-737-300 CWT explosion at Ninoy Aquino International Airport, Manila, Philippines, the exact source of ignition was never established. However, the Safety Board later concluded, "It is possible that the combination of a faulty float switch and damaged wires providing a continuous power supply to the float switch may have caused an electrical arc or overheating of the switch leading to the ignition of the center fuel tank vapor."[23]

An Air Force study[24] of data from 1986 to 1989 mishaps[25] caused by electrical failures found 652 records, of which 326 were examined in detail. Of the 326 reports, 49 involved "conductors" (typically aircraft wiring) and 51 involved "connectors" of numerous types. The study concluded the following:

RA164 Center Wing Tank Wire Bundle Analysis Report, December 17, 1996, indicates bundle No. W186 contains 12 192-volt wires for the flight engineer panel lighting.

[20] Wires that were not isolated or shielded and that were routed in bundles with other wires, some of which carried power for other airplane systems.

[21] Wire markings identified the general N93119 aircraft wiring as (Boeing Specification) BMS13-42A, marketed by Raychem. The wire was sold commercially under the trade name "Poly-X." Other types of wire were also used in the construction of B-747 airplanes.

[22] The Safety Board was permitted to review a report regarding a military C-130 fuel tank explosion that occurred after improper maintenance created a short circuit that created an ignition source in the fuel tank. The airplane identification and the date and location of the incident have not been released.

[23] National Transportation Safety Board. August 1, 1990. Safety Recommendations A-90-100 through -103.

[24] Contract F33615-89-C-5647, completed January 1989, to develop a handbook for the evaluation of electrical components in aircraft accident investigations.

[25] According to the Air Force, there are four classes of mishaps in the Norton database [of USAF mishaps]. Classes A, B, and C generally represent in-flight conditions that result in some damage to the aircraft. The fourth class includes potential mishaps, which may be the result of unusual conditions observed during maintenance or preflight checks.

> The majority of aircraft mishaps involving electronics are related to interconnection problems. Interconnection problems are primarily due to wiring and connector failures. Chafing, which results in electrical arcing of wiring, and corrosion, which results in the electrical breakdown in connectors, appear to be the dominate failure mechanisms.

Such findings are not unique to military mishaps. For example, on July 19, 1997, a Lufthansa B-747 freighter (D-ABZC) was on final approach to JFK International Airport, New York, when seven circuit breakers popped in the cockpit. Afterward, maintenance personnel found 47 (non-FQIS) wires burned in more than 8 inches of the affected wire bundle; the wires were located beneath the oxygen bottles in the "cheek" area to the right of the forward cargo compartment. The wires led to the leading and trailing edge flaps, landing gear circuitry, and the anticollision lights. Circuitry for the wing flap asymmetry detection and a flap electrical drive motor led to the burned area, and each of those components needed replacement. The airplane had been purchased from another carrier and, in April 1993, was modified by a third company to the freighter configuration. Lufthansa found that this airplane and five others that were modified by the same company had metal drill shavings and other debris in that area of the wire bundle. The incident demonstrated the danger of allowing metal shavings to remain on wiring and the possibility of introducing enough electrical energy into unrelated circuits to damage electrical components.

In addition to investigating the potential for introducing energy into FQIS wires from direct short circuits, tests were conducted to determine the energy that can be induced into unshielded FQIS wires by electromagnetic inductance (EMI). Laboratory tests[26] have shown that EMI can introduce elevated levels of energy into FQIS wiring, and sparks can be induced by adding foreign material to the fuel probes, thus creating spark gaps. This amount of energy was only found during tests in which a spark gap was artificially created between the Lo-Z (outer fuel probe electrode or terminal) and ground. To date, testing has not duplicated those results on an airplane. The investigation of this issue is continuing.

Wire shielding and physical separation each provide EMI and chafe protection for the inner conductor and a path to ground for short circuits from other wires and are widely used in airplanes. However, two of the three recovered FQIS wires from N93119 that had been routed between the CWT and the cockpit in a woven sleeve were not protected from EMI or chafing by shielding or separation from other wires. Also, BMS13-42A wires that were found routed from the cockpit end of the FQIS harness to the E/E compartment were not shielded or separated. In 1974, Boeing incorporated an overall shield around all three CWT FQIS wires routed between the CWT and flight engineer panel; in 1980, Boeing added further shielding to FQIS wires behind the flight engineer panel. However, these wiring changes were not required for previously manufactured airplanes, such as N93119. In its October 27, 1997, letter, Boeing

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[26] Tests were conducted to Boeing specification to create transient voltages and sparks by switching electrical power on and off in wires that had been laid parallel to the CWT bundle. Tests induced up to 0.060 millijoules of energy in the CWT harness, exceeding the API practice 2003 reference for an MIE requirement of 0.025 millijoules.

acknowledged the additional benefits of shielding, but wrote that the shielded wire was used to correct for electrical noise in the FQIS wires (not for EMI or chafe protection).

The Safety Board recognizes the difficulty and expense associated with physically separating FQIS wires from other wires and adding shielding to FQIS wires on in-service air carrier airplanes. Access is limited behind avionic racks and at bulkhead electrical connectors, and rewiring is labor intensive. However, the separation of the FQIS from other power sources by shielding and separation can protect fuel tank wires from power sources that can potentially ignite an explosive vapor in a fuel tank. The Safety Board believes that the FAA should require in B-747 airplanes, and in other airplanes with FQIS wire installations that are corouted with wires that may be powered, the physical separation and electrical shielding of FQIS wires to the maximum extent possible.

Because of the variety of latent potential ignition sources found in B-747 fuel tanks, and the variety of means by which energy can be introduced into FQIS wires, the Safety Board does not believe that correcting wiring deficiencies and addressing system failures would fully protect the B-747 CWT and other fuel tanks against all potential ignition sources. Total FQIS wire shielding or separation from other wires would be very difficult to change in airplanes already in service and would not address failures within system components, such as fuel gauges, ground refueling volumetric shutoffs, and data acquisition units. Unless the volatility of fuel tank vapors can be eliminated as a potential hazard, electrical power surge suppressers may be the most effective method of preventing the FQIS from becoming an ignition source. On December 1, 1997, the FAA issued a notice of proposed rulemaking applicable to B-747-100, -200, and -300 series airplanes that agreed with this premise and would require either the installation of components for the suppression of electrical transients by electromagnetic interference, or the shielding and separation of the electrical wiring of the FQIS.

Surge suppressors installed where FQIS wires enter fuel tanks could provide added protection against excessive power surges in the FQIS system, regardless of origin. Surge protection systems are used in a range of devices, from autopilots to personal computers. Boeing has successfully used electrical surge suppression in other applications, but has noted that extreme care would have to be used in an FQIS application to account for possible influences on system operation and failure modes. Because the basic concepts of most capacitance FQIS systems are similar, the Safety Board believes that the FAA should require, in all applicable transport airplane fuel tanks, surge protection systems to prevent electrical power surges from entering fuel tanks through FQIS wires.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Issue, as soon as possible, an airworthiness directive to require a detailed inspection of fuel quantity indication system wiring in Boeing 747-100, -200, and -300 series airplane fuel tanks for damage, and the replacement or the repair of

any wires found to be damaged. Wires on Honeywell Series 1-3 probes and compensators should be removed for examination. (A-98-34)

Issue an airworthiness directive to require the earliest possible replacement of the Honeywell Corporation Series 1-3 terminal blocks used on Boeing 747 fuel probes with terminal blocks that do not have knurled surfaces or sharp edges that may damage fuel quantity indication system wiring. (A-98-35)

Conduct a survey of fuel quantity indication system probes and wires in Boeing 747s equipped with systems other than Honeywell Series 1-3 probes and compensators and in other model airplanes that are used in Title 14 Code of Federal Regulations Part 121 service to determine whether potential fuel tank ignition sources exist that are similar to those found in the Boeing 747. The survey should include removing wires from fuel probes and examining the wires for damage. Repair or replacement procedures for any damaged wires that are found should be developed. (A-98-36)

Require research into copper-sulfide deposits on fuel quantity indication system parts in fuel tanks to determine the levels of deposits that may be hazardous, how to inspect and clean the deposits, and when to replace the components. (A-98-37)

Require in Boeing 747 airplanes, and in other airplanes with fuel quantity indication system (FQIS) wire installations that are corouted with wires that may be powered, the physical separation and electrical shielding of FQIS wires to the maximum extent possible. (A-98-38)

Require, in all applicable transport airplane fuel tanks, surge protection systems to prevent electrical power surges from entering fuel tanks though fuel quantity indication system wires. (A-98-39)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: March 17, 1998

In reply to refer to: A-98-40

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On June 17, 1997, just after takeoff from Las Vegas, Nevada, a Reno Air McDonnell Douglas MD-83 airplane, N875RA, operating as flight 516, experienced an uncontained failure of the No. 1 (left) engine, a Pratt & Whitney (P&W) JT8D-219, serial number (SN) 708177. The airplane returned to Las Vegas and landed without further incident. The airplane was operating on an instrument flight rules flight plan under the provisions of Title 14 Code of Federal Regulations Part 121 as a regularly scheduled passenger flight from Las Vegas to Colorado Springs, Colorado. The investigation of this incident is continuing; however, information gathered thus far raises safety concerns that the National Transportation Safety Board believes require Federal Aviation Administration (FAA) action.

During the aircraft's ascent after takeoff, high-pressure turbine (HPT) parts were liberated from the engine. Inspection of the airplane revealed two exit holes in the engine nacelle and one hole in the fuselage in a nonpressurized compartment of the airplane. Postincident examination of the engine revealed four exit holes in the combustion chamber fan ducts just forward of the HPT rotational plane, yet the HPT case (front turbine case) was not penetrated. Two sections of the HPT case rear flange were bent outward and forward, and were disengaged from the low-pressure turbine (LPT) case (rear turbine case) front flange, creating two large openings. The HPT shaft had sheared at the No. 4 ½-bearing scavenge oil holes; all the HPT blades fractured transversely across the blade airfoil; and all the 2nd-stage turbine vanes were missing.

The engine was equipped with an HPT containment shield (see figure 1) as required by Airworthiness Directive (AD) 93-23-10.[1] The AD was issued on January 18, 1994, and is

[1] The containment shield is intended to prevent engine HPT parts from being liberated and causing secondary damage to the airplane or injuring passengers. The shield is positioned radially outward from the rotational plane of the HPT blades. The width of the containment shield is approximately 4 inches, and its support attaches to the HPT case rear flange. The support, although it provides some containment capability, is primarily to buttress and properly position the containment shield.

applicable to all JT8D-209, -217, -217A, -217C, and -219 turbofan engines. The containment shield is a clam shell design consisting of two half-shields joined by clevis plates and supported by a cantilevered shield support attached to the HPT rear flange. Considerable impact damage (engine debris) was observed on the inner diameter (ID) of the containment shield; however, the shield remained intact. The impact of turbine material on the lower shield shifted it outward and aft from its normal installed position, buckling its support. First-stage turbine blades and 2nd-stage turbine vanes had exited the engine through the openings between the HPT and LPT case flanges and deflected off the containment shield ID while exiting the engine and before striking the airframe.

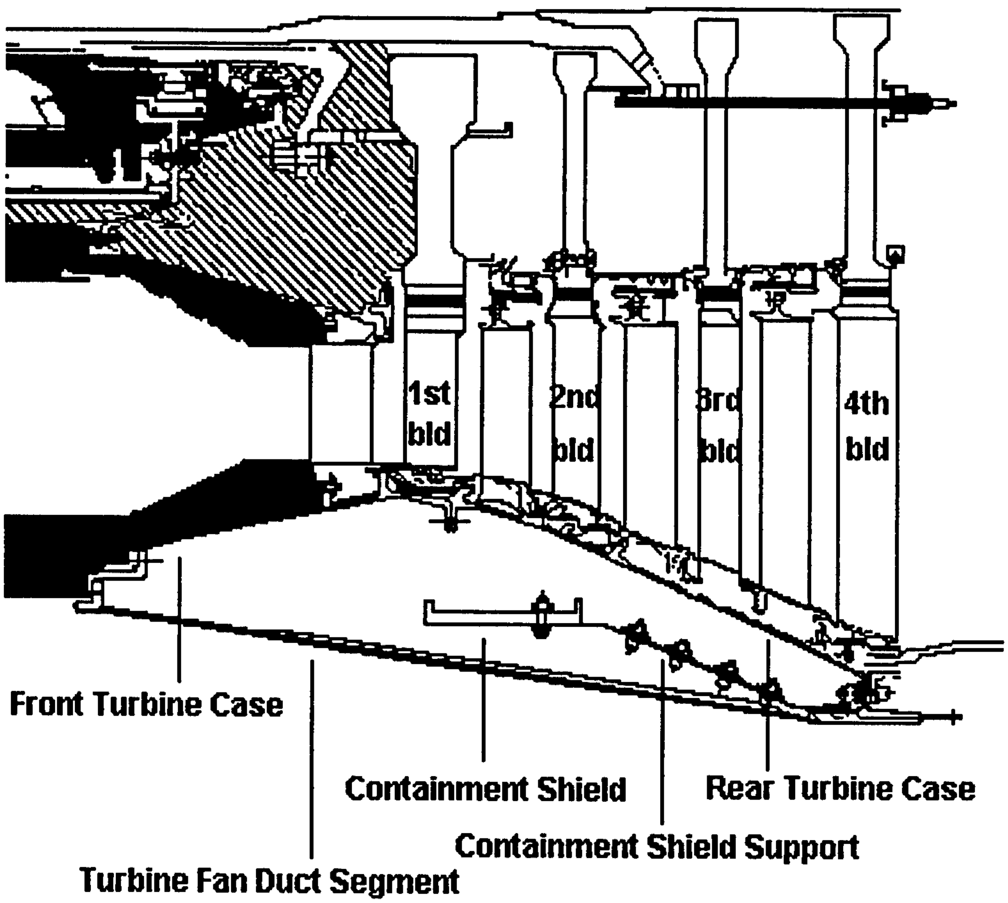

Figure 1 Containment Shield Configuration

Another incident involving a P&W JT8D-219 uncontained turbine failure that resulted from a sheared HPT shaft occurred on July 13, 1996, on a Centennial Airlines[2] McDonnell Douglas MD-80 airplane, en route from Dusseldorf, Germany, to the Canary Islands. Like the Reno Air incident, the failed engine was equipped with an HPT containment shield, which was not

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[2] Centennial Airlines is a Spanish-registered supplemental air carrier based in Palma de Mallorca, Spain.

penetrated; however, exiting turbine parts impacted the shield ID, buckled its support, and shifted the shield from its normal position. The buckled support allowed the exiting turbine parts to deflect off the shield and penetrate the engine nacelle.

On November 7, 1991, after the JT8D-200 series engine had experienced six HPT shaft fractures, three resulting in the liberation of turbine parts, P&W issued Alert Service Bulletin (ASB) 6053 to incorporate a containment shield for JT8D-209, -217, 217A, -217C, and -219 engines.[3] Subsequently, P&W issued Service Bulletin (SB) 6122 on May 20, 1993, to address premature wear of the support slip joint caused by buffeting of the shield. The basic design stayed the same; however, new hardware with hardfacing[4] on the mating surfaces was incorporated. AD 93-23-10 required JT8D-200 series engines to be outfitted with a containment shield as instructed by P&W ASB 6053, Revision 7, dated May 24, 1993. The FAA's Engine Certification Manager, ANE-140, issued a letter on June 28, 1994, approving SB 6122 as an equivalent means of compliance to AD 93-23-10.

The Reno Air and Centennial Airlines incidents have shown that the JT8D-200 series engine HPT containment shield design is inadequate to prevent all turbine parts from being liberated because the support is insufficient to sustain the shield in the proper location when impacted by some exiting turbine material. In addition, the incidents have shown that the containment shield is not wide enough nor the sidewalls deep enough to ensure that exiting material will be contained under a variety of exit paths. The Safety Board is concerned that the current containment shield cannot prevent HPT part liberation and therefore believes that the FAA should evaluate the current P&W JT8D-200 series engine HPT containment shield required by AD 93-23-10 and, if shown by evaluation, require that it be replaced with an HPT containment shield that would provide a larger coverage area and more impact resistance and durability.

Therefore, as a result of the ongoing investigation of this incident, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Evaluate the current Pratt & Whitney JT8D-200 series engine high-pressure turbine (HPT) containment shield required by Airworthiness Directive 93-23-10 and, if shown by evaluation, require that it be replaced with an HPT containment shield that would provide a larger coverage area and more impact resistance and durability. (A-98-40)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

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[3] At the time ASB 6053 was issued there had been six documented HPT fractures resulting from No. 4 and 5 bearing compartment oil fires, three of which have resulted in uncontained events.

[4] Hardface is a seal facing of high hardness that is applied to a softer material, such as by flame spraying, plasma spraying, electroplating, nitriding, carburizing, or welding for better wear resistance.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: June 25, 1998

In reply refer to: A-98-41 through -42

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 28, 1997, at 1222 mountain standard time, American Airlines flight 230, a McDonnell Douglas MD-82, sustained a left engine turbine section fire and tailpipe fire shortly after takeoff from the Tucson International Airport, Tucson, Arizona. The flight was operating in visual flight rules conditions under Title 14 Code of Federal Regulations (CFR) Part 121 as a scheduled domestic passenger flight from Tucson to Dallas-Fort Worth, Texas. The 5 crewmembers and 118 passengers sustained no injuries.

The captain stated that he heard a loud bang as the aircraft was climbing through 1,800 feet, and the left engine "spooled down." A left engine fire extinguisher bottle was activated to control the fire, and the engine was secured. The flight returned and landed on runway 29R. As airport rescue and firefighting (ARFF) personnel extinguished a fire in the left engine tailpipe, the flightcrew attempted to contact them on the ground control frequency. By the time radio contact was made, approximately 16 passengers had exited the aircraft via the forward left door slide, and several other passengers had climbed onto the right wing to evacuate. The flight attendant stated that she saw firetrucks and firemen outside the cabin door and one fireman "gave me the thumbs up, then I proceeded to open the door." The firefighter stated that he gave the "thumbs up" hand signal to stop the evacuation. The ARFF personnel stopped the passengers from evacuating the aircraft and directed them back inside the airplane. The remaining passengers eventually deplaned using portable stairs.

During a debriefing session of the incident, ARFF personnel determined that the evacuation of this aircraft was not necessary and that the aircraft could have been safely towed to a gate. The passengers could have safely deplaned at that point. During the discussions, ARFF personnel stated that if they had a direct means of communicating with the flightcrew, unnecessary evacuations such as this one could be avoided.

On July 8, 1996, about 0741 central daylight time, Southwest Airlines flight 436, a Boeing 737-200, N53SW, received minor damage during a rejected takeoff (RTO) from runway

20C at the Nashville Metropolitan Airport, Nashville, Tennessee. The airplane was operated as a regularly scheduled domestic passenger flight under the provisions of 14 CFR Part 121. The airplane stopped approximately 750 feet off the departure end of runway 20C, about 100 feet east of the extended centerline. The 5 crewmembers and 122 passengers evacuated using the emergency slides. One passenger received serious injuries, and four passengers received minor injuries during the emergency evacuation.

After completing the emergency checklist and announcing over the public address system that the passengers should remain seated, the captain saw that the fire department equipment had arrived. The captain and the ARFF on-scene supervisor established voice communications through the captain's open cockpit window. The ARFF supervisor reported to the captain that the tires were smoking and deflating. The right main landing gear ignited and was immediately extinguished with foam. After hearing a fire warning and without determining the location or severity of the fire, the flight attendants initiated an aircraft evacuation. During the evacuation, the left main landing gear ignited and was immediately extinguished. Although the flightcrew was able to communicate with the ARFF personnel through the open cockpit window, the Nashville Metropolitan Airport Authority determined that a designated radio frequency might have allowed the ARFF personnel to advise the flightcrew about the situation in a more timely manner. Therefore, the flightcrew might have been able to coordinate with the flight attendants and prevent an evacuation. As a result of this accident, a designated frequency was assigned for use during accidents and incidents at the Nashville airport.

Eight major airports in the United States have instituted a designated frequency for emergency use.[1] On June 19, 1996, Delta Air Lines flight 229, a Boeing 767-332, returned to the Salt Lake City Airport, Salt Lake City, Utah, after the flightcrew detected a fire in the right engine; although the fire was still burning, ARFF personnel and the flightcrew decided not to evacuate the airplane while ARFF members extinguished the fire. Although before this incident the Salt Lake City Airport did not have a designated frequency, the ground controller provided the flightcrew and ARFF personnel a discrete frequency on which to communicate that resulted in improved emergency response. The flightcrew was able to taxi the aircraft to a gate under the airplane's own power. The passengers and crew sustained no injuries.

The Tucson and Nashville incidents illustrate the need for flightcrews and ARFF personnel to have the ability to communicate with each other directly. A designated radio frequency allows ARFF personnel to issue critical information concerning the exact nature of, and hazards associated with, an emergency in progress. Consequently, the Safety Board believes that the FAA should establish a designated radio frequency at all airports certified under Title 14 CFR Part 139 that allows direct communication between ARFF personnel and flightcrew members in the event of an emergency and take appropriate measures to ensure that air traffic control personnel, ARFF personnel, and pilots are aware of its designation.

[1] The airports are located in Covington/Cincinnati, Ohio (CVG); Honolulu, Hawaii (HNL); Seattle, Washington (SEA); Nashville, Tennessee (BNA); Los Angeles, California (LAX); Fort Lauderdale, Florida (FLL); Philadelphia, Pennsylvania (PHL); and Boston, Massachusetts (BOS).

The Safety Board is also concerned that ARFF personnel may not be able to communicate with a flightcrew if power is lost or if the flightcrew must abandon the cockpit. Following RTOs and emergency landings, flightcrews may shutdown the airplane's electrical power, rendering two-way radio communications ineffective. Consequently, the Safety Board believes that the FAA should develop a universal set of hand signals for use between ARFF personnel and flightcrews and flight attendants for situations in which radio communication is lost.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Establish a designated radio frequency at all airports certified under Title 14 CFR Part 139 that allows direct communication between airport rescue and firefighting (ARFF) personnel and flightcrew members in the event of an emergency and take appropriate measures to ensure that air traffic control personnel, ARFF personnel, and pilots are aware of its designation. (A-98-41)
>
> Develop a universal set of hand signals for use between airport rescue and firefighting personnel and flightcrews and flight attendants for situations in which radio communication is lost. (A-98-42)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: June 25, 1998

In reply refer to: A-98-43

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On December 26, 1995, a Piper PA-46-310P, N800SJ, lost engine power during cruise flight and crashed at Ocala, Florida, while attempting to perform an emergency landing.[1] The pilot and one of the passengers were seriously injured. The National Transportation Safety Board's examination of the engine disclosed detonation damage to the No. 6 cylinder piston and scoring of the piston sidewalls at five of the six cylinders. The engine turbocharger's turbine-inlet temperature (T.I.T.) gauge was tested and found to read low; at the 1,750°F test point (maximum continuous T.I.T.), the gauge indicated only about 1,640°F.

The Safety Board determined that the probable cause of the accident was "oil starvation resulting in connecting rod failure in three of the six cylinders due to lack of lubrication." At the request of the Safety Board, maintenance personnel checked the calibration of T.I.T. gauges in nine PA-46 series airplanes (seven PA-46-350P models and two PA-46-310P models). Three of the gauges indicated correctly at the 1,750°F test point; the other gauges indicated 60° to 110° low.

On April 26, 1996, Piper issued Service Bulletin (SB) No. 995A, "Turbine Inlet Temperature (T.I.T.) System Calibration and Probe Replacement." Under "PURPOSE" the bulletin states the following:

> Field reports indicate that the accuracy of the existing [T.I.T.] probe may decrease over time in service. The corrosive and very hostile environment experienced in the exhaust system has dictated that Piper establish a 250 hour service life for the T.I.T. probe. In addition, a new calibration procedure has been established to check the accuracy of the indicator and wiring. Failure to calibrate the T.I.T. system or to replace the T.I.T. probe as prescribed, may lead to inaccurate or erroneous T.I.T. indications, and possible engine damage.

[1] For more detailed information, read Brief of Accident MIA96FA049 (enclosed).

This Service Bulletin consists of two (2) PARTS which address the T.I.T. system:

PART I provides for the application of a new calibration procedure for the T.I.T. system (one time).

PART I I requires an initial replacement of the T.I.T. probe at the compliance time listed above and requires repetitive replacement by establishing a normal service life. (On PA-46-350P aircraft only.)

Failure to comply with this Service Bulletin may result in damage to or shorten the life of the powerplant. Compliance must occur at or within the compliance times indicated.

The calibration procedure is applicable to Lewis T.I.T. gauges, Piper Part Number 471-008 or 548-011 and is required each time a T.I.T. gauge is replaced or if a system error is suspected. SB 995A indicates that T.I.T. probe replacement must occur at cylinder changes, at engine overhauls, or if other T.I.T. system maladies become apparent.

The PA-46-310P Pilot's Operating Handbook (POH) indicates that the airplane's cruise fuel mixture setting should be established at 50° lean of peak T.I.T. The POH outlines a procedure for doing so and indicates that although the procedure differs from conventional leaning procedures, the airplane should never be operated in cruise with a fuel mixture setting other than 50° lean of peak T.I.T. The POH contains the following precautionary note in connection with establishing the peak T.I.T.:

> Maximum continuous T.I.T. is 1750°F. Temporary operation up to 1800°F is permitted in order to define peak T.I.T. In no case should the aircraft be operated more than 30 seconds with a T.I.T. in excess of 1750°F.

The Safety Board agrees with the importance of adhering to Piper's cruise fuel mixture setting procedure. However, in view of the accident involving N800SJ and the critical importance of adhering to the engine turbocharger's T.I.T. limitation, the Safety Board is concerned that use of inaccurate T.I.T. gauges to define the peak T.I.T. may result in or contribute to inadvertent engine damage and an in-flight loss of power. Therefore, the Safety Board believes that the FAA should issue an airworthiness directive, applicable to both Piper PA-46-310P and PA-46-350P model airplanes, requiring compliance with Piper SB 995A, "Turbine Inlet Temperature (T.I.T.) System Calibration and Probe Replacement."

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Issue an airworthiness directive, applicable to both Piper PA-46-310P and PA-46-350P model airplanes, requiring compliance with Piper Service Bulletin No. 995A, "Turbine Inlet Temperature (T.I.T.) System Calibration and Probe Replacement." (A-98-43)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 04/15/98

MIA96FA049
FILE NO. 1991 12/26/95 OCALA, FL AIRCRAFT REG NO. N800SJ TIME (LOCAL) - 22:45 EST

MAKE/MODEL -Piper-PA-46-310P
ENGINE MAKE/MODEL -Continental TSIO-520-BE
AIRCRAFT DAMAGE -Substantial
NUMBER OF ENGINES -1
OPERATING CERTIFICATES -NONE
TYPE OF FLIGHT OPERATION -Personal
REGULATION FLIGHT CONDUCTED UNDER -14 CFR 91

	FATAL	SERIOUS	MINOR/NONE
CREW	0	1	0
PASS	0	1	5

LAST DEPARTURE POINT - KISSIMMEE, FL
DESTINATION - BIRMINGHAM, AL

AIRPORT PROXIMITY - Off airport/airstrip
AIRPORT NAME - OCALA REGIONAL/JIM TAYLOR
RUNWAY IDENTIFICATION - Unk/Nr
RUNWAY LENGTH/WIDTH (Feet) - Unk/Nr
RUNWAY SURFACE - Unk/Nr
RUNWAY SURFACE CONDITION - Unk/Nr

CONDITION OF LIGHT - Night (dark)

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 10.000 SM
WIND DIR/SPEED - 350 /003 KTS
TEMPERATURE (F) - 33
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 44

CERTIFICATES/RATINGS
Private
Single-engine land, Multiengine land
INSTRUMENT RATINGS
Airplane

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 1500
LAST 90 DAYS - 2
TOTAL MAKE/MODEL - 500
TOTAL INSTRUMENT TIME - Unk/Nr

During cruise flight at 14,000 feet mean sea level, the engine failed. The flight was vectored to a nearby airport bu the pilot flew toward another airport and crashed in a residential area. Examination of the engine revealed 1.8 quar of oil were drained and 3 of the 6 connecting rods were failed due to lack of lubrication. Also, detonation damage t the No. 6 cylinder piston was noted and scoring of piston sidewalls was noted at 5 of the 6 cylinders. Evidence of heat discoloration was noted to the connecting rod journals for 3 of the 6 cylinders. The aircraft TIT gauge, which had been miscalibrated by 30 to 40 degrees when the airplane was manufactured, was found to indicate 110 degrees Fahrenheit low near the maximum continuous point of 1,750 degrees. The air/oil separator hose to the scavenge pump w plugged about 10 inches along its length with a substance with a high lead content resulting in the recurring pilot report of excessive oil consumption. Due to the pilot complaint of excessive oil consumption 4 of the 6 cylinders we removed and replaced within the previous 6 months. About 1 month before the accident one of the cylinder pistons was removed and replaced after examination revealed piston sidewall damage consistent with detonation.

MIA96FA049
FILE NO.1991 12/26/95 OCALA, FL AIRCRAFT REG NO. N800SJ TIME (LOCAL)- 22:45 EST

Occurrence# 1 LOSS OF ENGINE POWER(TOTAL) - MECH FAILURE/MALF
Phase of operation CRUISE - NORMAL

Findings
1. ENGINE INSTRUMENTS,TIT GAGE - FALSE INDICATION
2. MAINTENANCE,CALIBRATION - IMPROPER - MANUFACTURER
3. MAINTENANCE,CALIBRATION - NOT PERFORMED - OTHER MAINTENANCE PERSONNEL
4. ENGINE ASSEMBLY,PISTON - SCORED
5. FLUID,OIL - STARVATION
6. ENGINE ASSEMBLY,CONNECTING ROD - FAILURE,TOTAL

Occurrence# 2 IN FLIGHT COLLISION WITH OBJECT
Phase of operation EMERGENCY DESCENT/LANDING

Findings
7. OBJECT - TREE(S)
8. ATC CLEARANCE - DISREGARDED - PILOT IN COMMAND

The National Transportation Safety Board determines the probable cause(s) of this accident was:
oil starvation resulting in connecting rod failure in three of the six cylinders due to lack of lubrication. Contributing to the accident was the failure of the pilot to adhere to a ATC vector toward the nearest airport following engine failure which resulted in the airplane flying past the vectored airport and subsequent collision with trees.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: July 10, 1998

In reply refer to: A-98-44 through -58

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On August 7, 1997, at 1236 eastern daylight time,[1] a Douglas[2] DC-8-61, N27UA, operated by Fine Airlines Inc. (Fine Air) as flight 101, crashed after takeoff from runway 27R at Miami International Airport (MIA) in Miami, Florida. The three flightcrew members and one security guard on board were killed, and a motorist was killed on the ground. The airplane was destroyed by impact and a postcrash fire. The cargo flight, with a scheduled destination of Santo Domingo, Dominican Republic, was conducted on an instrument flight rules flight plan and operated under Title 14 Code of Federal Regulations (CFR) Part 121 as a Supplemental air carrier.

The National Transportation Safety Board determines that the probable cause of the accident, which resulted from the airplane being misloaded to produce a more aft center of gravity and a correspondingly incorrect stabilizer trim setting that precipitated an extreme pitch-up at rotation, was (1) the failure of Fine Air to exercise operational control over the cargo loading process; and (2) the failure of Aeromar to load the airplane as specified by Fine Air. Contributing to the accident was the failure of the Federal Aviation Administration (FAA) to adequately monitor Fine Air's operational control responsibilities for cargo loading and the failure of the FAA to ensure that known cargo-related deficiencies were corrected at Fine Air.[3]

Accident Scenario

The airplane departed controlled flight shortly after rotation, following an apparently normal taxi and takeoff roll. The Safety Board's correlation of data from the flight data recorder (FDR) and cockpit voice recorder (CVR) determined that the stick shaker warning activated

[1] Unless otherwise indicated, all times are eastern daylight time, based on a 24-hour clock.

[2] Boeing Commercial Airplane Group acquired the holdings of the Douglas Aircraft Company and McDonnell Douglas in 1997.

[3] National Transportation Safety Board. 1998. *Uncontrolled Impact With Terrain, Fine Airlines Flight 101, Douglas DC-8-61, N27UA, Miami, Florida, August 7, 1997.* Aircraft Accident Report NTSB/AAR-98/02. Washington, DC.

when the airplane was at an altitude of about 100 feet msl. According to the Board's performance study of the airplane's motion during the accident sequence, about 16 seconds after the start of rotation, at an altitude of about 300 feet msl, the airplane reached an extremely nose-high pitch attitude in the range of 30° and an angle-of-attack (AOA) approaching 20°, which resulted in an aerodynamic stall (an AOA of 15° was sufficient to bring the airplane into the stall region). Subsequently, the AOA decreased toward 10°, and the pitch decreased to below 20°, resulting in a brief recovery from the stall, followed by another AOA increase into the stall region 5 seconds later (the stall warning stopped at 12:36:12 and resumed at 12:36:17).

The ground scars and the airplane damage indicated that at impact, the pitch angle was about 23°, while the flight path angle was about 26° down. This resulted in an AOA of at least 49° at the time of impact, consistent with the airplane being in a deep stall. A continued stall is also consistent with the stick shaker stall warning and engine surge sounds recorded on the CVR in the final moments of the flight and the witness statements about pitch attitude during flight and at ground impact. The performance study showed that once the initial stall was reached, full recovery was unlikely because of the airplane's low altitude and the airplane's rapidly decreasing performance. Thus, based on analysis of FDR, CVR, and postaccident airplane performance data and on witness statements, the Safety Board concludes that the airplane pitched up quickly into a stall, that it recovered briefly from the stall, that it stalled again, and that recovery before ground impact was unlikely once the stall series began.

Airplane Handling Characteristics

The weight and balance form provided to the flightcrew showed a calculated center of gravity (CG) location at 30.0 percent mean aerodynamic cord (MAC). However, the Safety Board and the Douglas Products Division calculated a CG of 32.8 percent MAC based on a loading scenario developed from information provided by Aeromar loaders, Fine Air flight follower testimony, pallet weight documentation, and postaccident communication with Aeromar representatives. The Safety Board also notes that a relatively small addition to and/or redistribution of cargo could have moved the airplane's CG beyond the aft limit of 33.1 percent MAC.

The succession of errors made by Fine Air and Aeromar in loading this flight and the deficiencies in the Aeromar and Fine Air loading procedures identified during postaccident FAA inspections made it impossible to precisely determine the weight and CG from the data that were available following the accident. For example, the cargo destined for the accident airplane was listed as weighing 89,719 pounds when it arrived at Aeromar's warehouse in big pacs and boxes. After being put on pallets and secured with plastic covers and netting, the cargo was listed on the Aeromar pallet load sheet as weighing 88,923 pounds, or 796 pounds less than the cargo weighed at arrival. Pallets and netting added an additional 275 pounds per pallet (or about 4,400 pounds to the total cargo weight). Based on postaccident Aeromar statements that the entire cargo delivered to Aeromar was loaded onto pallets for shipment on the accident airplane, the actual cargo weight could have been at least 94,119 pounds. Thus, the weight of the cargo that Aeromar provided to Fine Air could have been 5,196 pounds more than listed on the pallet weight form (which resulted in the CG of 32.8 percent MAC). This additional weight could have had a significant effect on the CG of the airplane, depending on how it was distributed through the cabin.[4]

In February 1998, the Safety Board conducted a series of tests using a DC-8 full motion flight training simulator. Multiple takeoff attempts were simulated using aircraft weight, flap settings, and thrust values equivalent to the accident conditions and a range of CG values. The simulator flight tests suggest that at 33 percent MAC, the column inputs recorded on the accident airplane's FDR might have been sufficient to prevent the pitch-up and stall. Further, at 35 percent MAC, the simulator reached the stall condition more quickly than did the accident airplane. Although adequate control power existed from the elevators and pitch trim to recover the airplane at 35 percent MAC, successful recovery required an immediate and aggressive control input response (full forward column, which could be assisted by nose-down trim). Pilots involved in the simulation reported that their immediate control inputs were successful for the conditions tested because they were anticipating the pitch-up at rotation.[5] At CG values aft of 35 percent, the airplane was increasingly subject to autorotation tendencies well before rotation speed and to tail strike on the runway, which did not occur during the accident. However, based on the loading information and the simulator tests, the Safety Board concludes that the CG of the accident airplane was near or even aft of the airplane's aft CG limit.

Statements by the flightcrew on the CVR show that the stabilizer trim was set during taxi-out at 2.4 units ANU, the value appropriate for the trim setting and CG of 30 percent MAC that the flightcrew had been given. The number of trim-in-motion tones recorded on the CVR during the recovery attempt and the full-nose-down trim setting found at impact were also consistent with the flightcrew having set 2.4 units during taxi.

The Safety Board considered the effects of different aircraft loadings on CG location and the associated pitch trim settings. The investigation found that 13 pallets had been moved farther aft than indicated on the loading sheet. At 88,923 pounds total cargo weight, moving the 13 pallets aft (and turning pallet four 90°) would have shifted the CG from 24.0 percent MAC (requiring 5.4 units airplane nose up [ANU] pitch trim) to 32.4 percent MAC (1.0 units ANU). Further, if the cargo weight were 94,119 pounds, the CG would have shifted from 24.0 percent MAC (5.4 units ANU) to 32.8 percent MAC (0.9 units ANU). Thus, pushing the 13 pallets aft shifted the CG farther aft by at least 8 percent MAC. Further, because the accident airplane's stabilizer trim setting was 2.4 units ANU, the Safety Board concludes that the CG shift resulted in the airplane's trim being mis-set by at least 1.5 units ANU (2.4 minus 0.9 units at 94,119 pounds).

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[4] Based on a payload weight of 94,119 pounds, the Safety Board calculated that the redistribution of 250 pounds from the front to the rear of the airplane could have resulted in a CG of 33.2 percent MAC. Redistribution of 1,200 pounds from the front to the rear could have resulted in a CG of 35 percent MAC.

[5] In its investigation of a 1993 accident involving a United Airlines DC-8-54F in Detroit, the Safety Board found that "recovery of the airplane at rotation was possible if immediate nose-down trim was applied along with full forward elevator input." However, the Safety Board concluded that "once the airplane left the ground and started to accelerate, recovery was improbable." (See National Transportation Safety Board. 1983. *United Airlines Flight 2885, N8053U, Douglas DC-8-54F, Detroit, Michigan, January 11, 1983.* Aircraft Accident Report NTSB/AAR-83/07. Washington, DC.)

Such a mistrim would cause a greater than expected nose-up pitching moment. This would be exacerbated by the lighter control column forces that result from an aft CG location. Consequently, the Safety Board concludes that the aft CG location and mistrimmed stabilizer presented the flightcrew with a pitch control problem; however, because the actual CG location could not be determined, the severity of the control problem could not be determined.

The simulator flight tests could not replicate the accident flight precisely because of limitations inherent in the simulator; for example, the aerodynamic data upon which the simulator's performance was based may not accurately model the actual airplane's performance in ground effect (during rotation and initial climb) or when high-pitch rates are present near stall. Further, the simulator's performance characteristics become invalid in the stall region. Timing of the control column movements in the simulated takeoff attempts was also a factor. Evaluation of the simulator data showed that small differences in the timing of inputs produced dramatically different results 5 to 10 seconds later.

Unfortunately, it was also not possible to replicate precisely the flightcrew's control inputs because, due to insufficient documentation, the control column position (CCP) positions recorded by the accident airplane's FDR could not be converted into precise position values but rather represented relative motion. The Safety Board could not determine with certainty the correlation between the CCPs recorded by the FDR and actual positions of the control column on the airplane. Thus, the simulator tests did not permit the Safety Board to determine precisely the response of the accident airplane to the flightcrew's control inputs.

Flightcrew Actions

Statements recorded on the CVR indicated that the flightcrew recognized a problem with airplane handling about the pitch axis immediately as the airplane rotated. At 12:35:51.5, 1.6 seconds after the "rotate" call out and about 1 second after the first officer began to move the control column aft, the captain began his "easy easy easy easy" remark. Based on FDR data, it appears that the captain made his statement before the airplane's pitch attitude had rotated significantly nose-up. The CCP moved aft a total of about 5°. About 2 seconds later (at 12:35:53.5), still during rotation, the FDR showed forward movement of the control column. The magnitude of the forward movement was about 4° from its most aft position; however, about 2 seconds after the start of the forward motion it was moved aft again. At 12:35:57 the control column was moved forward, and it reached its most forward position (presumed to be the full forward limit of the control column) at 12:36:01.

The first officer's continued aft column input for 2 seconds after the captain began his "easy easy easy easy" remark exacerbated the pitch-up that was developing from the mistrimmed stabilizer. However, the first officer's 2-second response time in responding to the captain was understandable in light of the physiological, neurological, and cognitive contributors to reaction time. Further, is not clear that the flightcrew would have recognized the need for abrupt, aggressive, and sustained action at the initiation of the pitch-up.

Regarding the first officer's subsequent aft control column input (at 12:35:54.5), the Safety Board notes that flightcrews are trained to avoid rapid and excessive control inputs and to gauge the results of control inputs before making additional corrections. In moving the control column forward and aft, the first officer might have been attempting to judge what nose-down control column inputs were required to correct the airplane's developing pitch-up attitude. The Safety Board also notes that the application of immediate and forceful nose-down control inputs at rotation is counter-intuitive and contrary to the training and experience of line flightcrews.

According to the CVR, the first trim-in-motion sound occurred a fraction of a second before the first aural stall warning (at 12:36:02), indicating that the trim inputs were not initiated until the accident airplane was already very close to a stall. Although aggressive nose-down trim inputs were made thereafter and until the trim reached its full nose-down position, about a 5-second delay occurred between the flightcrew's first attempt to control the pitch-up with nose-down column inputs and the first inputs of nose-down trim.

If the first officer had chosen to trim the airplane in the first, critical moments during and after rotation, he would have obtained a greater nose-down pitching moment and might have been able to correct most, or all, of the mistrim condition, preventing the airplane from stalling. The Safety Board considered the possibility that a more experienced pilot, particularly one who had previously encountered an aft-loaded, out-of-trim condition on takeoff, might have assessed the situation more rapidly and engaged the airplane's powerful pitch trim more quickly to aid in the recovery attempt. For example, if the captain had been flying the takeoff, he might have more quickly recognized the need for and applied a trim correction.

Although the Safety Board was unable to determine precisely how far aft the CG was located and thus the extent to which the airplane was mistrimmed, the Safety Board concludes that the mistrim of the airplane (based on the incorrectly loaded cargo) presented the flightcrew with a situation that, without prior training or experience, required exceptional skills and reactions that cannot be expected of a typical line pilot. Although the unanticipated nature of the rapid pitch-up was an important aspect of the situation, the Safety Board concludes that training for flightcrews in dealing with misloading, miscalculated CG, and mistrimmed stabilizers would improve the chances for recovery from such situations. However, there is no current FAA requirement for air carriers to provide flightcrews with training in identifying and responding to a rapid-pitch-up during rotation from a mistrimmed stabilizer. Therefore, the Safety Board believes that the FAA should require all 14 CFR Part 121 air carriers to provide flightcrews with instruction on mistrim cues that might be available during taxi and initial rotation, and require air carriers using full flight simulators in their training programs to provide flightcrews with Special Purpose Operational Training that includes an unanticipated pitch mistrim condition encountered on takeoff.

Cargo Document Preparation, Communications, and Ramp Delivery Procedures

In the hours before the accident flight, the exchange of airplanes required a series of significant cargo paperwork changes by Fine Air flight followers and Aeromar employees. Fine Air flight followers determined that the cargo weight would be 87,923 pounds and that the CG and trim would be 30 percent MAC and 2.4 units ANU if the airplane was loaded as directed.

Fine Air flight followers refined the weight and balance calculations for N30UA, the originally assigned airplane, to accommodate weight limitations for N27UA and then defined the pallet sequence to produce a more aft CG of 30 percent MAC (moving the pallet in position 13 to position 17 and leaving position 13 vacant). Fine Air flight followers stated that these changes were communicated to Aeromar by fax and by direct telephone conversations. However, the fax communications were the subject of conflicting statements by personnel from both companies. Further, there was no evidence that the revised paperwork was picked up by the Aeromar security guard responsible for the accident flight's cargo.

Although the Fine Air flight follower told Aeromar to reduce the weight of pallet "G" by 1,000 pounds (reducing the total cargo weight to 87,923 pounds) because of the landing weight restrictions for N27UA, that weight was not removed by Aeromar. Therefore, the final load sheet provided to the flightcrew was in error by an additional 1,000 pounds. The mistake was missed by Aeromar and Fine Air. The Fine Air flight follower also improperly recorded the pallet weight in position 17 as 5,860 pounds on the final load sheet, rather than 5,960 pounds as recorded by Aeromar on the pallet loading form.

The Safety Board's investigation also revealed errors in the printed load sheet form. The form indicated that it was for a DC-8-61 airplane, but one part of the form that affected the CG calculation (the fuel distribution scale) was based on data for DC-8-62 and -63 airplanes. The printed Fine Air load sheet form also incorrectly listed the maximum weight allowable for pallet position 18 as 6,088 pounds, instead of the correct weight of 3,780 pounds, which resulted in pallet position 18 exceeding its weight limitation by 1,247 pounds on the accident flight. Calculations based on this form resulted in a computed CG that was farther aft than the actual CG. The proper loading form would have yielded a 26.5 percent MAC CG for 87,923 pounds rather than 30 percent MAC. The built-in CG errors could have accounted for reported flightcrew requests to Fine Air flight followers to provide more rearward CGs to improve the flying characteristics of their airplanes. However, moving the CG aft would not correct the mistrim but would lighten control forces somewhat.

Weight and balance errors were a persistent problem at Fine Air previously identified by two Department of Defense (DoD) inspections (in 1994 and 1996 respectively) and two FAA inspections (a preaccident national aviation safety inspection program [NASIP] inspection and a postaccident regional aviation safety inspection program [RASIP] inspection). Shortly after the 1996 DoD inspection, Fine Air proposed redesigning its load sheet "as an interim measure until they automate weight and balance computations." However, this redesign was not accomplished before the accident and would likely not have revealed the fuel loading and pallet weight errors in the load sheet. Further, the Safety Board found during its investigation that Fine Air's load sheet, revised after the accident, also contained errors and discrepancies when compared to Douglas data, and that Fine Air's stabilizer trim setting data sheet also contained errors. The Safety Board notes with disappointment that Fine Air revised the load sheet form incorrectly after errors were found after the accident, and that FAA principal inspectors assigned to Fine Air failed to detect this mistake. Based on an examination of Fine Air and Aeromar loading documents and statements from Fine Air and Aeromar employees, the Safety Board concludes that procedures used by Fine Air and Aeromar to prepare and distribute cargo weight pallet distribution forms and final weight and balance load sheets were inadequate to ensure that these documents correctly reflected the true loading of the accident airplane. The Safety Board is concerned that similar problems may exist at other carriers. Therefore, the Safety Board believes that the FAA should conduct an audit of all CFR Part 121 supplemental cargo operators to ensure that proper weight and balance documents are being used, that the forms are based on manufacturer's data or other approved data applicable to the airplane being operated, and that FAA principal inspectors confirm that the data are entered correctly on the forms.

There was conflicting information about whether the Aeromar and Fine Air employees involved in the loading operation were aware of the airplane change and of the changes in the loading instructions for the accident airplane. Aeromar's vice president stated that a company security guard picks up loading paperwork at Fine Air "immediately prior to the loading of a plane" or when the security guard delivers the cargo to the Fine Air ramp. The Fine Air flight follower who calculated the original load for N30UA stated that the Aeromar security guard in charge of the cargo picked up the paperwork with the cargo before 0600 on the day of the accident. However, the flight follower who went on duty after 0600 stated that the security guard did not return to pick up the revised weight distribution form. Although Fine Air flight followers stated that they faxed updated weight distribution and loading information to Aeromar before the flight, Aeromar's vice president stated that such a practice was "neither customary or usual." Based on interviews with Aeromar employees, the security guard assigned to the flight's cargo would have already been on duty at the Fine Air ramp when Fine Air flight followers said that they faxed the load changes to Aeromar. Testimony by Aeromar loaders indicated that cargo pallets were arranged on the ramp for loading according to the weight distribution form calculated for N30UA. Therefore, the Safety Board concludes that the security guard was not aware of the airplane change, and that he instructed Aeromar loaders to load the airplane in accordance with the weight distribution form he possessed for N30UA.

Airplane Loading Operations

Although there were conflicting statements about several aspects of the loading process, Aeromar cargo handlers' descriptions of the initial loading were consistent with the planned weight and balance configuration for N30UA, with pallet positions 2 and 17 initially left vacant. However, Aeromar cargo handlers stated that pallets could not be secured with locks during the initial loading. A subsequent check by the Aeromar supervisor determined that pallet locks would not latch in the rear of the airplane because pallet edges were not positioned properly, preventing locks from engaging on each edge of adjacent pallets.[6] According to the statements of the loaders and supervisor, in an attempt to correct this, all pallets from position 5 aft were pushed back one position each, which resulted in pallet position 17 being filled and position 5 being emptied. Pallet 4 was turned 90° and pushed back, which resulted in the pallet occupying all of position 5 and part of position 4.[7] According to loader statements, pallet 3 was secured by

[6] The Aeromar loading supervisor said the locks would not latch because cargo extended over the sides of the pallets. Because of conflicting testimony, it could not be determined who first identified the problem with the loading and who issued instructions to rearrange the load.

[7] These actions were initiated by the loading crew or its supervisors and did not adhere to any planned loading configuration for the cargo on this airplane, which was calculated in Fine Air operations by the Fine Air flight follower.

locks on the front and back sides, which would have left position 2, by the cargo door, empty, with position 1 (with locks up) by the forward (cockpit) bulkhead. Thus, based on loader statements about how the airplane was first loaded and subsequent changes to the cargo's configuration, the Safety Board concludes that the accident airplane (N27UA) was initially loaded according to Fine Air's load distribution for N30UA; further, the final load configuration did not match the planned load for either airplane.

Loaders gave contradictory statements about the number of pallet engaged locks from positions 6 through 18 when the rearrangement and loading was completed. The Aeromar loading supervisor, who was responsible for ensuring that pallet locks were in place, stated that he put up several locks near position 18, and that he relied on other loaders to put locks up forward of that position. However, the Safety Board found considerable evidence indicating that few of the pallet locks were engaged. For example, 57 of the 60 locks recovered from the wreckage (from a total of 85 installed) were found in the unlocked position, and postaccident testing found no evidence of cracking, shearing, or elongation associated with impact damage and failure. Although it was the Aeromar loading supervisor's responsibility (according to his job description) to ensure that the locks were in place, he did not verify that they had been latched, relying instead on the thoroughness of loaders working in what was described as a hot, cramped, and stifling environment.[8]

Moreover, the Fine Air supervisor, who was the forklift driver (and, according to all parties involved, was not acting in a supervisory capacity) for the loading of the accident airplane, stated that when he was in charge of loading operations he always checked to make certain that the locks were up around pallet position 1. He said that he did so because these locks were readily visible to the flight engineer, who otherwise might insist on a reload if locks were down or missing. This implies that he believed it was less important to engage the locks that were not visible to the flight engineer, and suggests a casual attitude about the importance of aircraft weight and balance.

Cargo loading requires the coordination of a team under the direction of a supervisor to accomplish a multistep process, including identifying the appropriate pallet, loading the pallet onto the airplane, positioning the pallet inside the airplane, and securing the pallet in position. These basic steps were not followed during the loading of the accident flight. When it became evident to the loading crew that the cargo would not secure properly, decisions were made about pallet positioning and load security that suggested a desire to complete the job quickly. Little or no attempt was made to determine whether these changes would adversely affect the airplane in flight. Therefore, the Safety Board concludes that the Aeromar cargo loading supervisor failed to ensure that the pallets were loaded according to an approved load plan (in this case neither load plan was followed) and failed to confirm that the cargo was properly restrained.

Because there were vacant spaces in the cargo distribution and the cargo was not properly secured, the Safety Board considered whether shifting cargo at rotation could have contributed to the accident. Unsecured cargo pallets could shift during acceleration, and more significantly

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[8] For example, loaders said the temperature inside of the airplane was "just like an oven." However, it could not be determined to what extent, if any, these conditions contributed to the misloading of the airplane.

during rotation, if there were empty pallet positions between unsecured pallets. However, when Aeromar loaders pushed all of the cargo pallets from position 5 rearward one position and turned pallet 4 sideways into position 5, this created a line of contiguous pallets from position 5 to position 18, the aft-most cargo pallet position in the airplane. This suggests that the misloaded, aft-heavy condition existed at the time of rotation and was not caused by cargo shifting as the airplane's deck angle increased. However, based on loader statements that cargo extended over the sides of some pallets (which prevented the locks from being engaged), some shifting of cargo and additional compression might have occurred as the airplane's deck angle increased. The Safety Board concludes that a significant shift of cargo rearward at or before rotation did not occur and was not the cause of the initial extreme pitch-up at rotation; although, cargo compression or shifting might have exacerbated the pitch-up moment as the pitch increased.

Following the accident, the FAA's RASIP inspection team found numerous problems related to Fine Air's loading operations, including improperly secured and broken pallets, frayed and broken netting, and deficiencies in the areas of weight and balance control, cargo weighing, and security. These areas were also addressed in a consent agreement Fine Air signed with the FAA in September 1997, in which the operator agreed to revise its cargo handling system and procedures, including its "maintenance program for cargo pallets and cargo restraint devices, cargo pallet loading procedures, cargo weighing procedures...aircraft loading procedures [and] aircraft weight and balance procedures."

As part of its revised procedures, Fine Air developed a loading supervisor certification form that loading supervisors must sign to indicate that the load was placed on the airplane according to plan and restrained properly. In addition, the revised Flight Operations Manual (FOM) breaks down the loading process into specific procedures and steps to be followed by the loading supervisor when loading the airplane,[9] which helps to standardize the loading process.

However, the load certification form only contains an overall statement attesting to the fact that loading was performed in accordance with Fine Air's loading requirements. Cargo loading supervisors and cargo handlers work under difficult conditions that can include physical strain, time pressure, extreme temperatures, and nighttime hours, all of which can affect job performance. Thus, the Safety Board concludes that the difficult work environment of cargo loaders has the potential to cause loading errors if the loading process is not adequately structured to compensate for the detrimental environmental effects on human performance. However, these conditions can be mitigated by developing independent controls to ensure that critical steps in the loading process are completed properly. Therefore, the Safety Board believes that the FAA should require carriers operating under 14 CFR Part 121 to develop and use loading checklists to positively verify that all loading steps have been accomplished for each loaded position on the airplane and that the condition, weight, and sequencing of each pallet is correct.

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[9] In addition to the loading supervisor certification form, Fine Air made significant revisions to its FOM, AOM, and other documents outlining new load planning procedures, loader and supervisor responsibilities, and flightcrew responsibilities after resuming operations in October 1997 under the consent agreement. The airline stated that it now has provisions in place to ensure that pallets are built properly, that weights are verified (e.g., pallets are now weighed by Fine Air before being loaded), and that loading operations are thoroughly supervised.

Operational Control

Fine Air's wet lease agreement with Aeromar called for Aeromar to provide "fuel, loading and unloading at all stops," but stipulated that Fine Air retained operational control of all flights, and that all servicing was to be done under the supervision of Fine Air employees. Fine Air's operational control responsibilities were also defined in the company's FOM and spelled out in an addendum to Fine Air's lease agreement with Aeromar. Although 14 CFR Part 121.537 outlines supplemental air carrier operational control responsibilities, the principal operations inspector (POI) assigned to Fine Air stated that operational control for loading was not specifically addressed in the regulations. Further, the Safety Board could identify no such requirement in these regulations. However, the FAA stated in an October 1997 letter to Fine Air that under provisions of Part 121, "no aspect of operational control can be negotiated away...[including] loading of cargo as it relates to weight and balance requirements, cargo restraint requirements and hazardous materials requirements."

Although the terms of the wet lease agreement (later determined by the FAA to be a "transportation" or "charter" agreement) stated that Fine Air retained operational control, Fine Air managers stated that before the accident the company did not supervise loading operations carried out by Aeromar. In addition, Fine Air did not weigh palletized cargo delivered by Aeromar or have other procedures in place to verify cargo weights and the accuracy of the load form provided to the crew by Fine Air flight following. The Safety Board concludes that Fine Air failed to exercise adequate operational control of loading operations conducted by Aeromar on the accident flight as required by Part 121, the operational control terms of its lease agreement with Aeromar, and its own operating policy. Further, the Safety Board concludes that Fine Air's failure to exercise adequate operational control was causal to the accident by creating an operational environment in which cargo was loaded into Fine Air airplanes without verification of pallet weights and proper load distribution and by fostering a management philosophy that allowed airplanes to be dispatched without verification and control procedures in place to ensure that load-related, flight safety-critical tasks had been accomplished.

Loader Experience and Training

Four of the Aeromar cargo handlers had previous experience in air cargo operations in Miami. However, one cargo handler and the Aeromar loading supervisor had no experience in air cargo operations before employment with Aeromar. The Aeromar loading supervisor was hired about 3½ months before the accident and had been promoted to supervisor about 2 weeks before the accident on the basis of his performance. All cargo loading personnel interviewed by Safety Board investigators accurately described how to engage and disengage cargo locks and demonstrated a general knowledge of proper cargo loading procedures.

Air carriers are currently not required to provide initial classroom training or recurrent training for personnel involved in cargo handling. Training for loading personnel at Aeromar and Fine Air was described as on-the-job training. Aeromar cargo handlers stated that they did not receive any classroom training and that their supervisor had provided verbal instructions and information about the job of loading an airplane when they first were assigned to the cargo ramp. Aeromar cargo handlers who had previously worked at Fine Air indicated that while at Fine Air they received no classroom training. The Fine Air loading supervisor also stated that he had received no classroom training for cargo loading. Although it appears that on-the-job training was an effective method of instruction for the basic technical job requirements, the misloading of the accident airplane indicates that loaders did not recognize the importance of loading an airplane consistent with the calculated weight and balance plan, or the importance of properly restraining the cargo. Therefore, the Safety Board concludes the loaders who loaded the accident airplane were not aware of the potentially catastrophic consequences of misloading the airplane and the failing to properly secure cargo, and that this contributed to the accident.

It is the Safety Board's understanding that cargo handler positions are typically entry-level positions characterized by relatively high rates of turnover. The Safety Board is concerned that because of a high turnover rate it can be difficult to control the quality of instruction delivered through on-the-job training. Because it is critical to the safety of flight to ensure that cargo has been loaded according to plan and properly restrained, all individuals associated with the loading process must be provided with consistent and comprehensive training in airplane loading.

After the accident, the FAA issued air transportation bulletin Handbook Bulletin for Airworthiness and Air Transportation (HBAT) 97-12 to FAA Order 8400.10 "Air Transportation Operations Inspector's Handbook."[10] In this bulletin the FAA states the following:

> Currently, part 121, section 121.400 prescribes the requirements applicable to each certificate holder for establishing and maintaining a training program for crewmembers, aircraft dispatchers, and other operations personnel. While the term "other operations personnel" is not currently defined in this subpart, it is evident that employees of a certificate holder who have the duty to supervise the loading of an aircraft or who qualify and authorize other persons to perform this function, must be trained on the certificate holder's procedures.

The bulletin encouraged principal inspectors to review any training program operators had for their cargo loading supervisors.

In the consent agreement issued after the accident, the FAA required Fine Air to "review and revise as necessary a training program for cargo handlers and other personnel responsible for cargo handling and aircraft loading." In response, Fine Air created a training program for cargo loader supervisors and cargo handlers[11] that included approximately 7 hours of training including curriculum areas covering the following:

- basic aerodynamics
- weight and balance for ground handlers

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[10] The bulletin was issued on September 5, 1997, as a Joint Flight Standards Handbook Bulletin; therefore, it was also added to FAA Order 8300.10, "Airworthiness Inspector's Handbook" as HBAW 97-12.

[11] Fine Air's training manual states that "This category of training is for an employee whose job description includes the identification of, positioning, direct and indirect handling of cargo to be loaded on FINE AIR aircraft to ensure the proper loading and handling of cargo aboard company aircraft." In addition to initial training there are provisions for recurrent training in this program.

- safe handling of aircraft cargo
- pallet building, loading, and unloading.

The Safety Board considers the steps taken by Fine Air to provide formal training to its cargo handling personnel to be a significant improvement in its training program because the curriculum is standardized and training modules go beyond the technical requirements of the job. However, the Safety Board recognizes that the consent agreement was directed only to Fine Air and is concerned that the training programs of other operators may suffer from similar deficiencies. Further, HBAT 97-12 only encouraged inspectors to examine operators' training for supervisory cargo loading personnel, and inspectors do not have the appropriate guidance material to evaluate training programs in cargo handling operations.[12] Thus, the Safety Board concludes that formal training is necessary to ensure that cargo handling personnel receive standardized instruction on safety-critical aspects of the loading process.[13] Therefore, the Safety Board believes that the FAA should require training for cargo handling personnel and develop advisory material for carriers operating under 14 CFR Part 121 and POIs that addresses curriculum content that includes but is not limited to, weight and balance, cargo handling, cargo restraint, and hazards of misloading and require all operators to provide initial and recurrent training for cargo handling personnel consistent with this guidance.

Flightcrew Load Verification Responsibilities

According to the Fine Air Aircraft Operation Manual (AOM) used at the time of the accident, the flight engineer was required to verify that at least three cargo pallet locks were locked at each position loaded with a pallet during his preflight check in Miami. However, Fine Air representatives told Safety Board investigators that it would have been "unlikely" for a flight engineer to make this check of the entire airplane during routine operations in Miami.[14] Other company personnel indicated that in Miami airplanes were typically loaded before flightcrews arrived and some loads did not provide sufficient clearance for the flight engineer to verify the status of the locks in positions aft of the cargo door.[15] The Safety Board recognizes that Fine Air changed the flight engineer's preflight checklist after the accident as part of a review and revision of its loading procedures and that new controls are now in place to ensure that the locks are

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[12] FAA Order 8400.10 does not provide guidance on evaluating training programs for cargo loading operations. In contrast, FAA Order 8400.10 and advisory circular (AC) 120-60 provide guidance material for FAA inspectors reviewing the initial and recurrent training programs that air carriers establish as part of their ground deicing and anti-icing programs under 14 CFR 121.629.

[13] At least one industry trade union, the International Association of Machinists and Aerospace Workers, stated that it offers training to ramp workers and other aviation personnel on the impact on flight safety of routine duties such as cargo loading, hazardous materials handling, and deicing operations.

[14] According to Fine Air's FOM, it is the joint responsibility of the first officer and the flight engineer to ensure proper airplane loading at outstations.

[15] Pallets are typically configured so that there is access to the area around the cargo door, to verify that door has been secured. Therefore, it is likely that the flight engineer was able to verify locks were up on positions 1 and 3 in the accident airplane. Loaders told Safety Board investigators that if these locks were not locked and visible to the flightcrew they risked being asked to reload. The current Flight Engineer's Preflight expanded checklist (page 6-12-19, issued 9/26/97, revision 35) only requires a check that all pallet locks installed in the airplane be operable. It no longer requires the engineer to ensure that a minimum of three pallet locks per position be used and locked.

engaged. However, at the time of the accident the flight engineer faced inconsistent guidance and expectations about this task. Thus, the Safety Board concludes that although the flight engineer was required to ensure that all cargo pallet locks were locked, company operating procedures and practices in MIA hindered him from accomplishing this task. Further, the Safety Board is concerned that such differences between flightcrew requirements for loading oversight and actual operational procedures may exist at other air carriers. Therefore, the Safety Board believes that the FAA should review the cargo loading procedures of carriers operating under 14 CFR Part 121 to ensure that flightcrew requirements for loading oversight are consistent with the loading procedures in use.

Although they possessed the airplane's load sheet (based on numbers provided by Fine Air flight followers) and the flight engineer was required to conduct a visual inspection, the accident flightcrew had no practical way to verify the airplane's weight and balance and gross weight before takeoff. However, the Safety Board notes that an electronic system has been in widespread use for years in both cargo and passenger operations that provides flightcrews with a digital readout in the cockpit of weight and balance and gross weight values. The STAN (Sum Total Aft and Nose) system uses pressure transducers to convert main gear and nose gear shock strut air pressure to an electronic signal. The cockpit readout, on the flight engineer's instrument panel, provides the flightcrew with an independent, direct measure of the airplane's gross weight and CG. Cockpit instrumentation showing these values would have added a critical last-minute safeguard for this flightcrew. Thus, the Safety Board concludes that if the flightcrew had had an independent method for verifying the accident airplane's actual weight and balance and gross weight in the cockpit, it might have alerted them to the loading anomalies, and might have prevented the accident. Therefore, the Safety Board believes that the FAA should evaluate the benefit of the STAN and similar systems and require, if warranted, the installation of a system that displays airplane weight and balance and gross weight in the cockpit of transport-category cargo airplanes.

FAA Surveillance and Oversight

The FAA's RASIP inspection of Fine Air following the accident found anomalies that the inspection team's report characterized as "an indication of a systemic problem at Fine Airlines." Echoing findings in previous preaccident FAA and DoD inspections, the RASIP report stated that inspectors had found problems in the areas of weight and balance control, cargo weighing, the accuracy of pallet weights, the condition of pallets and netting, and the condition of airplane cargo compartments and equipment. All of these findings, the report concluded, had "an impact on the safety of flight."

FAA inspectors assigned to Fine Air and Miami Flight Standards District Office (FSDO) managers stated that before the Fine Air accident, there was "no guidance," or "minimal guidance," in FAA written directives for the surveillance of cargo operations, and that there were no guidelines on how to evaluate the condition of pallets, netting, and other cargo equipment. The principal maintenance inspector (PMI) assigned to Fine Air described his attitude to cargo inspection before the accident as "to us, cargo is cargo." However, the team leader of the postaccident RASIP inspection at Fine Air, who is a PMI assigned to the United Parcel Service certificate, stated that specific guidance should not have been needed to discover the problems the RASIP inspection team found relating to the condition of pallets, nets, and cargo deck flooring, noting that these problems were "evident." Moreover, during an en route inspection to Santo Domingo conducted a week before the accident, the Fine Air PMI was able to identify numerous loading problems, including damaged pallet netting, improper cargo loading, and a scale that was not in a location to weigh pallets. Although the PMI wrote a letter to Fine Air after the accident (on August 11, 1997) that asked Fine Air to amend its work cards for "C" checks in the areas identified as deficient during the en route inspection, no enforcement case was opened based on these findings, and the PMI did not take any other direct action to correct the immediate problem.

The manager of the FAA's Miami FSDO stated that he believed that the FAA surveillance of Fine Air's operations was "adequate" before the accident, but acknowledged that inspectors were "concentrating their emphasis on other areas," not on cargo loading. The FAA regional director, based in Atlanta, whose jurisdiction included the Miami FSDO, stated that "it's hard to define quality of surveillance," but acknowledged that the problems found in the RASIP should have been found earlier by the principal inspectors assigned to Fine Air.

Although the regional director noted that local inspectors can become bogged down in "certificate maintenance" (manual revisions, training program oversight, and other paperwork duties) at the expense of surveillance, even when they are aware of the findings of special inspections conducted by other teams, the director conceded that operations involving older airplanes, less experienced crews, and a "smaller [cost/profit] margin...are a concern." Nevertheless, cargo loading and weight and balance problems were repeatedly identified at Fine Air before and after the accident, and inspectors assigned to Fine Air had discovered and documented at least some of these problems before the accident. Therefore, the Safety Board concludes that the FAA inspectors assigned to Fine Air failed to ensure that known deficiencies in Fine Air's cargo operations were corrected. Thus, these problems went beyond a lack of broader FAA inspector guidance on inspecting cargo operations, and the FSDO manager conceded that senior FAA management had expressed "concern that we're not proactive."

Although the problems with the Miami FSDO's surveillance program at Fine Air pertained mostly to a failure to act on findings, the Safety Board is also concerned that the surveillance of cargo loading operations is not specifically required in the annual work programs established for FAA flight standards inspectors. The Safety Board concludes that the entire sequence of cargo loading operations, from preparation of the pallets/containers through the information provided to flightcrews, has a direct effect on flight safety and should not be neglected by the FAA surveillance program, particularly for the cargo air carriers operating under 14 CFR Part 121. Therefore, the Safety Board believes that the FAA should require all principal inspectors assigned to 14 CFR Part 121 cargo air carriers to observe, as part of their annual work program requirements, the complete loading operation including cargo weighing, weight and balance compliance, flight following, and dispatch of an airplane.

During its investigation of this accident, the Safety Board found numerous preaccident indicators of problems not only at Fine Air, but at other cargo Part 121 operators under the jurisdiction of the Miami FSDO. In the case of Fine Air, these included the findings of previous NASIP, RASIP, and DoD inspections at Fine Air. In another situation similar to Fine Air, Miami-based cargo operator Millon Air voluntarily ceased operations on October 24, 1996, following an FAA inspection conducted after a Millon Air Boeing 707 freighter crashed in Manta, Ecuador, two days earlier on October 22, 1996. (In its investigation of several previous accident and incidents involving Millon Air, the Safety Board had found a series of FDR-related maintenance deficiencies). In 1995, the FAA suspended the operating certificate of another Miami-based Part 121 cargo and passenger carrier, Arrow Air, after an inspection found evidence of serious safety violations. Thus, the Safety Board concludes that the Miami FSDO lacked clear management policies to ensure that sufficient and appropriate surveillance was conducted and that surveillance results were acted upon; further, the FSDO was not aggressive in its inspection and management of the Fine Air certificate and this contributed to the accident.

Such cases were not limited to the Miami FSDO. In the case of the May 11, 1996, accident in the Florida Everglades involving a ValuJet DC-9-32, FAA postaccident inspections found numerous maintenance and operational deficiencies that resulted in the air carrier ceasing operations when it entered into a consent agreement with the FAA in June 1996. Deficiencies in ValuJet's operations had been thoroughly documented in an FAA report prepared before the accident and in RASIP and NASIP inspections conducted before the accident. The February 14, 1996, report noted "some weakness in the FAA surveillance" of the airline and inattention to "critical surveillance activities." The report, which recommended that consideration be given to the "immediate recertification" of the airline, was not provided to the Atlanta FSDO or to ValuJet until after the accident. These maintenance and operations-related problems, which were identified by FAA regional management as requiring greater scrutiny and concern, should have been sufficient to alert the FAA's senior managers to the need for more aggressive surveillance and before the Fine Air accident. Since the accident, FAA officials have acknowledged that under current oversight programs what they described as system failures like Fine Air are difficult to detect, and that the existing system of surveillance was inadequate. Moreover, a recent GAO report on the effectiveness of FAA inspector surveillance concluded that many FAA inspections "are not thorough or structured enough to detect many violations," and that inspectors often do not initiate enforcement actions because "doing so entails too much paperwork." Based on these repeated problem indicators and the FAA's acknowledgement of the shortcomings of its current oversight system, the Safety Board concludes that the deficiencies found in the Miami FSDO's oversight of Fine Air and other carriers in its jurisdiction are indicative of a broader failure of the FAA to adequately monitor air carriers, especially supplemental cargo carriers, in which operational problems had been identified.

Based on its investigation of the ValuJet Everglades and the Fine Air accidents, the Safety Board is also concerned about the effectiveness of the NASIP and RASIP inspection processes. In the case of each airline, preaccident inspections identified operational and airworthiness deficiencies. Although the findings of these inspections resulted in short-term corrective actions for the specific items that were found to be deficient, the inspections failed to identify and address systemic problems that were found in postaccident inspections of both carriers and that resulted in their temporary shutdown. The FAA has developed considerable information on cargo-related problems from the results of two special emphasis ramp checks conducted after the Fine Air accident. However, the FAA Administrator noted in a March 3, 1998, memorandum that "much work remains to correct systemic problems with FAA's aviation safety inspection program." Further, FAA representatives told Safety Board investigators that "data collection, analysis and corrective actions are not well focused." The results of this investigation indicate that these deficiencies apply to both local FSDO surveillance and to NASIP and RASIP inspections. Thus, the Safety Board concludes that NASIP and RASIP inspections are not adequately identifying and addressing systemic safety problems that exist in air carrier operations at the time the inspections are conducted. Therefore, the Safety Board believes that the FAA should review its NASIP and RASIP inspection procedures to determine why inspections preceding these accidents failed to identify systemic safety problems at ValuJet and Fine Air and, based on the findings of this review, modify these inspection procedures to ensure that such systemic indicators are identified and corrected before they result in an accident.

The Safety Board notes current FAA initiatives to redesign and improve FAA oversight of air carriers, including the development and implementation of the Air Transportation Oversight System (ATOS) program designed to target resources and inspections to identify systemic safety problems. The Safety Board is also encouraged by the FAA's recent enforcement actions against cargo carriers based on standards developed after the Fine Air accident. Also encouraging are FAA proposals to better focus geographic inspector surveillance, planned changes in the new entrant carrier certification process and improved methods for the collection, analysis, and inspector access to FAA surveillance and safety trend data (the more effective use and dissemination of safety performance analysis system and program tracking and reporting system data). Although these and other proposed changes are in response to Safety Recommendation A-96-163, issued following the 1995 Tower Air accident, are steps forward, the Safety Board is concerned that some operators that may benefit most from additional scrutiny have not been included in the initial implementation phases of the ATOS program. The program is being launched at 10 of the nation's largest carriers, for which FAA surveillance is already considerable, and operational incidents and accidents are relatively rare.

Although it is understandable why the FAA wants to "refine the new model" before expanding to other sectors of the industry, the Safety Board is nevertheless concerned about the potential for delays inherent in the implementation of such a comprehensive redesign of the FAA surveillance system. Initial implementation at the 10 designated carriers is not scheduled until October 1998. Although the proposed changes to the FAA oversight system address the intent of Safety Recommendation A-95-163, the Safety Board will continue to monitor the FAA's progress in implementing these changes. Pending further action, the Safety Board reiterates its February 23, 1998, classification of Safety Recommendation A-95-163 as "Open—Acceptable Response."

However, the Safety Board remains concerned about the FAA's ability to successfully enhance its surveillance capability at current budget and personnel resource levels, especially at a time when the aviation industry is growing rapidly and increasing demands are being placed on the agency's certificate management system. Indeed, principal inspectors assigned to Fine Air stated that they needed assistance in accomplishing their tasks and that the number of en route inspections they conducted were reduced because of scheduling, workload, and budget constraints. Following a February 16, 1995, accident involving an Air Transport International DC-8-63, the Safety Board issued Safety Recommendation A-95-111, which asked the FAA to determine whether its budget and personnel resources were sufficient to maintain its surveillance programs adequately. Although the Safety Board in 1996 classified A-95-111 "Closed—Acceptable Action" following an FAA response stating that resources were "properly allocated to maintain oversight at an adequate level," the Safety Board concludes that, based on its investigation of the Fine Air accident, current FAA personnel and budget resources may not be sufficient to ensure that the quality of air carrier surveillance will improve. Therefore, the Safety Board believes that the FAA should evaluate the surveillance programs to ensure that budget and personnel resources are sufficient and used effectively to maintain adequate oversight of the operation and maintenance of both passenger and cargo carriers, irrespective of size.

Loss of FDR Data

The failure of the accident airplane's FDR to record 6 of the 11 required parameters of data hampered the Safety Board's investigation into the pitch-up and stall events that resulted in the airplane's departure from controlled flight. The FDR did not record information about engine data, airspeed, pitch and roll attitudes, vertical acceleration, and microphone keying, all of which would have been immensely useful in understanding the accident scenario.

The Safety Board has long been concerned about problems related to the absence of FDR data critical to accident investigations and has made a series of recommendations beginning in the early 1970s to improve FDR accuracy, expand the number of parameters, and require verification of parameter recordings. Continued concerns about the airworthiness of FDRs resulted in the Safety Board's issuing two recommendations to the FAA in 1991 (Safety Recommendations A-91-23 and -24) aimed at developing a permanent policy for FDR maintenance and recordkeeping. Further, in 1997, following a series of accidents that involved problems with recordings on retrofitted FDRs, the Safety Board issued two additional safety recommendations (Safety Recommendations A-97-29 and -30) asking the FAA to require readouts of retrofitted 11-parameter FDRs to ensure that all required parameters were being recorded properly and to complete, by January 1998, an FAA-promised AC addressing the installation and maintenance of FDRs.

The problems with the Fine Air FDR in this accident once again underscore the need for prompt action in determining the functionality and airworthiness of retrofitted 11-parameter FDRs, the importance of FDR certification and maintenance requirements, and the importance of accurate FDR documentation. In the case of Fine Air, in addition to the six parameters that were missing, the heading data were recorded on three parameters and in reverse. The Safety Board notes with concern that these deficiencies were found less than 4 months after a maintenance examination of the FDR that required the unit to be "downloaded into a computer capable of determining that all parameters are being recorded" and 3 months after it was overhauled and bench checked.

The Safety Board also notes with disappointment that the AC promised by the FAA to be issued by January 1998 has not yet been completed, even though the Safety Board provided a draft version of the AC upon request by FAA staff. The Safety Board has stated several times that inclusion of guidance relating to FDR maintenance documentation (which was addressed in FAA Notice N8110.65) into this AC would satisfy the intent of Safety Recommendations A-91-23 and -24. An AC addressing FDR maintenance and FDR certification would also satisfy the intent of Safety Recommendation A-97-30. However, the Safety Board is concerned that the AC, already delayed more than 7 years, still may not be produced in a timely manner. This AC is also essential to reduce retrofit problems that could occur on a much larger scale than those encountered during the less-sophisticated 11-parameter retrofit program. Accordingly, the Safety Board classifies Safety Recommendations A-91-23, A-91-24, and A-97-30 "Open—Unacceptable Response" pending the FAA's completion of the AC.

The Safety Board is also disappointed with the adequacy of the FAA's response to determine the airworthiness of retrofitted, 11-parameter FDRs, as requested in Safety Recommendation A-97-29 in May 1997. Although the FAA stated in a July 1997 response letter that it agreed with the intent of the recommendation and planned to require air carriers to perform readouts of all retrofitted 11-parameter FDRs within 180 days of the issuance of a new FDR flight standards bulletin (which became effective on December 15, 1997), the timetable intended for these readouts was not specified. For example, HBAW-97-13B, issued in response to Safety Recommendation A-97-29, made no mention of the 180-day timetable for readouts and only proposed scheduling FDR maintenance at "C" check intervals as part of the new FDR maintenance program guidelines it outlined.[16] Under the "C" check interval inspection plan described in the bulletin, Fine Air flight 101's FDR might not have been due for inspection until January 2001. This timeframe for completing a full readout of 11-parameter FDRs is not acceptable and does not address the intent of Safety Recommendation A-97-29.

Recent events suggest that the necessity for these readouts remains. Since the Fine Air accident, the Safety Board encountered yet another malfunction involving an 11-parameter retrofit, installed on an American Airlines Boeing 727 that landed short of runway 14R at O'Hare International Airport, in Chicago, Illinois, on February 9, 1998. Although the investigation is not complete, an initial readout of the accident airplane's FDR determined that data recorded on the elevator/pitch and longitudinal acceleration parameters were unuseable, resulting in the loss of information potentially critical to determining the cause of the accident. The Safety Board notes that this FDR malfunction occurred on an airplane maintained by a large international air carrier with extensive maintenance resources and substantial FAA oversight. FDR system documentation provided by the airline indicates that the elevator position sensor might have been installed incorrectly, and that this condition was not discovered during a functional test conducted at a "C" check in November 1997. Examination of the elevator parameter data suggested that the person who performed the functional test either wrote the results in the wrong place or that the elevator values were reversed, with the value for "full column forward" in the correct value range for "full column aft" and vice-versa. Although the Safety Board has not yet drawn a conclusion regarding the ground test, the Safety Board is concerned that these malfunctions might have resulted in improper parameter installation and/or maintenance.[17]

The Fine Air accident also highlights the importance of proper documentation of FDR maintenance actions and readout results. Although Fine Air's maintenance manual required that the accident airplane's FDR data be downloaded into a computer to determine that the parameters were being recorded properly, the maintenance job card that tracked the work

[16] At Fine Air, a C check interval occurs every 3,300 hours, or 36 months.

[17] Examination of the data recorded on the longitudinal acceleration parameter indicated that the data were more representative of data for lateral acceleration, suggesting that the accelerometer might have been incorrectly installed on the airplane, resulting in lateral, rather than longitudinal, data being recorded.

performed did not require this readout data to be printed or retained. Only a mechanic's signature was required to certify that the readout had been accomplished. Consequently, there was no way for another person to verify that the readout was correct. The Safety Board concludes that permanent documentation of FDR computer readouts is needed to later verify that such readouts have been properly accomplished.

Based on the continued discovery of malfunctioning 11-parameter FDRs and because the findings of this accident investigation indicate that it is advisable to require air carriers to maintain the records of FDR readouts, the Safety Board classifies Safety Recommendation A-97-29 "Closed—Unacceptable Action/Superseded" and believes that the FAA should require an immediate readout of all 11-parameter retrofitted FDRs to ensure that all mandatory parameters are being recorded properly; that the FDR system documentation is in compliance with the range, accuracy, resolution, and recording interval specified in 14 CFR Part 121, Appendix B; and require that the readout be retained with each airplane's records.[18]

The number of recent confirmed FDR malfunctions also suggests that the problem may go well beyond the scope of 11-parameter retrofits. Indeed, the number of problems encountered with 11-parameter FDRs suggests either inadequate installations or maintenance of FDR systems. The Safety Board is concerned that the problems encountered with 11-parameter FDR retrofits will not only continue, but worsen, without further corrective action as additional mandated parameters are added according to phase-in requirements under 14 CFR Part 121.343 and Appendix B.[19] Thus, the Safety Board concludes that current and proposed inspection intervals for FDRs (at each "C" check) are not adequate because of fleet utilization variables at many carriers. Therefore, the Safety Board believes that the FAA should require maintenance checks for all FDRs of aircraft operated under 14 CFR Parts 121, 129, 125, and 135 every 12 months or after any maintenance affecting the performance of the FDR system, until the effectiveness of the proposed AC and new FAA inspector guidance on continuing FDR airworthiness (maintenance and inspections) is proven; further, these checks should require air carriers to attach to the maintenance job card records a computer printout, or equivalent document, showing recorded data, verifying that the parameters were functioning properly during the FDR maintenance check and require that this document be part of the permanent reporting and recordkeeping maintenance system.

Although an FDR's primary function is to provide detailed flight information following an accident or incident, this detailed flight information is useful even in the absence of an accident or incident. The Safety Board notes that the FDR phase-in requirement and the quick access capabilities of modern solid-state FDRs offer operators the opportunity to develop and implement a flight operations quality assurance (FOQA) program. Analysis of downloaded

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[18] Appendix B outlines FDR specifications, including parameters, range, accuracy, sampling interval, and resolution.

[19] Under Part 121.343, all airplanes manufactured on or before October 11, 1991, with 30 or more seats will be required to have FDRs equipped with 22 channels (or 18 for those units that do not have flight data acquisition unitss no later than August 18, 2001). Airplanes manufactured after October 11, 1991, up to August 18, 2000, will be required to have FDRs with 34 channels. Transport airplanes manufactured between 2000 and 2002 will be required to have 57-parameter FDRs, and airplanes manufactured after August 18, 2002, will be required to have 88-parameter FDRs.

FOQA data enables operators to enhance crew and aircraft performance, to develop tailored training and safety programs, and to increase operating efficiency. FOQA programs can also be used to refine ATC procedures and airport configurations and to improve aircraft designs. Although FOQA programs based on the minimum 18 parameters called for in the FDR phase-in requirements would have some limitations, the potential safety and operational benefits of even a limited program are significant.

Because frequent FDR data downloads and data analysis are components of a viable FOQA program, the requirement for periodic readouts to validate the quality of the mandatory FDR parameters would likely be met if the operator corrected recording problems discovered in the readout. The need to download and analyze FDR would also require operators to maintain sufficient FDR system documentation to meet the Safety Board's needs in the event of an accident or incident.

In a May 1997 letter to the FAA, the Safety Board listed a series of accidents and incidents from 1991 through 1997 that involved problems extracting data from retrofitted FDRs. Because many of the problems encountered with retrofitted FDRs have resulted from improper installation and poor system documentation, the Safety Board is concerned that deficiencies may exist in the supplemental type certificate (STC) process; and that retrofit errors and problems are not being identified and corrected by FAA inspectors.[20] An FDR's primary function is to provide detailed flight information following an accident or incident; it does not otherwise affect the airworthiness of an aircraft. As a result, air carrier maintenance technicians may not view the FDR system as critical to the operation of the airplane, and FAA avionics inspectors may have little or no exposure to the complex data collection and recording features of FDR systems. Thus, the Safety Board concludes that FAA principal avionics inspectors (PAIs) may lack the experience and training to provide adequate oversight of FDR installations and continued FDR airworthiness requirements. Therefore, the Safety Board believes that the FAA should provide FAA PAIs with training that addresses the unique and complex characteristics of FDR systems. Further, the Safety Board believes that the FAA should create a national certification team of FDR system specialists to approve all STC changes to FDR systems.

Deficiencies in Fine Air's CAS Maintenance Program

A Safety Board review of the accident airplane's maintenance logs for the 90-day period before the accident indicated a significant number of recurring problems involving the engines, belly cargo doors, and thrust reversers. Although none of these problems were factors in the accident, the Safety Board is concerned because the continuing analysis and surveillance (CAS) program was designed to alert operators to repeat deficiencies and to facilitate prompt corrective maintenance action in problem areas. Fine Air's director of quality control stated that these repetitive repairs often involved "different parts" of "an old system." However, the number and similarity of the maintenance discrepancies on the accident airplane suggests that repeated problem indicators were either missed or ignored. Thus, the Safety Board concludes that Fine Air's CAS program was not as rigorous as its program description indicated and failed to result

[20] An STC authorizes alteration of an aircraft engine or other component that is operated under an approved-type certificate.

in the correction of systemic maintenance deficiencies. Therefore, the Safety Board believes that the FAA should direct the PMI assigned to Fine Air to reexamine the airline's CAS program and take action, if necessary, to ensure that repetitive maintenance discrepancies are being identified and corrected.

The Safety Board's review of the accident airplane's maintenance logs also found that all significant maintenance discrepancies were logged by flightcrews on return trips to Miami, where Fine Air's maintenance facilities are located. No significant entries were made at any outstation location. The FAA PMI assigned to Fine Air told Safety Board investigators that he had "raised concerns" with Fine Air management about flightcrews "having all their problems on final in Miami," adding that proving when the discrepancies actually occurred was impossible unless the inspector was accompanying the flightcrew on an en route inspection. In addition, an FAA PMI based in Milwaukee, Wisconsin, stated that such log entries "are common every day practice...if you're passenger or freight, that's standard." This inspector also described the difficulty inspectors encounter when trying to enforce proper logbook entry procedures, asking "how do you do something about it [prove the entries were intentionally deferred until the return leg]." In the case of Fine Air, the Safety Board found no evidence that corrective action was taken by the airline after the PMI raised his concerns to Fine Air management and no evidence of further FAA followup on the matter.

During its investigation of an uncontained engine failure on a Delta Air Lines MD-88,[21] the Safety Board determined that flightcrew members who found drops of oil on an engine bullet nose and two missing wing rivets did not have clear guidance on what constituted "maintenance 'discrepancies' and 'irregularities' and when to contact maintenance personnel and to log anomalies." Although the captain's decision to defer maintenance in Pensacola (the departure airport) until arrival in Atlanta, a Delta hub, appeared to have been contrary to Delta's FOM, Delta management later supported the flightcrew's failure to log the discrepancies or to contact maintenance.

The Safety Board is concerned that this return leg logging practice, which may be as widespread in the industry as it is difficult to verify, has become an unspoken, and largely tolerated, way of avoiding costly outstation repairs and flight delays. Safety Recommendation A-98-21, issued to the FAA as a result of the investigation of the Delta accident, was aimed at clarifying flightcrew responsibilities and when flightcrews "can, if at all, make independent determinations to depart when maintenance irregularities are noted." The recommendation called for POIs to review and clarify these policies at their respective operators. However, these policies may differ significantly among operators. Moreover, 14 CFR Part 121.363,[22] while outlining the airworthiness responsibilities of operators, contains no specific requirement to ensure that maintenance discrepancies are logged when they are discovered. According to 14 CFR Part

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[21] National Transportation Safety Board. 1998. *Uncontained Engine Failure, Delta Air Lines Flight 1288, McDonnell Douglas MD-88, N927DA, Pensacola, Florida, July 6, 1996.* Aircraft Accident Report NTSB/AAR-98/01. Washington, DC.

[22] Part 121.363, "Responsibility for Airworthiness," states that "each certificate holder is primarily responsible for...the airworthiness of its aircraft...[and] the performance of the maintenance, preventive maintenance...in accordance with its manual and the regulations of this chapter."

121.563, the pilot in command is required to "ensure that all mechanical irregularities occurring during flight time are entered in the maintenance log of the airplane at the end of that flight time" and to "ascertain the status of each irregularity entered in the log at the end of the preceding flight." The Safety Board is concerned that the term "flight time" is not specifically defined, and could be interpreted by flight crews as meaning at the end of the last flight of a multiple-leg duty day, instead of at the end of the flight during which the irregularity was discovered. Part 121.563 also does not address irregularities and specific logging responsibilities for irregularities found during preflight inspections.

Faced with a maintenance irregularity at an outstation, flightcrews (under schedule pressures and perhaps a management preference for home-base repairs when possible) may be reluctant to risk the delay that a logbook entry could incur. Language addressing specific logging requirements in Part 121.563 (that defined specific logging requirements or stated that logging is mandatory, rather than referring only to the general airworthiness of the airplane) would reduce ambiguity. This would require flightcrews, especially at outstations, to contact maintenance for a deferral or a decision to seek contract maintenance repairs before departing. Although there may be circumstances in which independent flightcrew evaluation of maintenance discrepancies is warranted, maintenance personnel are the best qualified personnel to make such determinations. Thus, the Safety Board concludes that Fine Air's maintenance logs for the accident airplane suggest a practice of logging significant maintenance discrepancies on return flights to Miami, where repairs were completed, and that such practices may be widespread in the industry. Further, the Safety Board concludes that although the PMI noted a pattern of logging entries on return flights to Miami and expressed his concerns to Fine Air management, no further action was taken either by the PMI or Fine Air management to address this problem. Therefore, the Safety Board believes that the FAA should amend 14 CFR Part 121.563 to specifically require that all discrepancies be logged when they occur and be resolved before departure through repair or deferral in consultation with (the certificate holder's or contracted) maintenance personnel.

As a result of the investigation of this accident, the National Transportation Safety Board recommends the following to the Federal Aviation Administration:

> Require all 14 Code of Federal Regulations Part 121 air carriers to provide flightcrews with instruction on mistrim cues that might be available during taxi and initial rotation, and require air carriers using full flight simulators in their training programs to provide flightcrews with Special Purpose Operational Training that includes an unanticipated pitch mistrim condition encountered on takeoff. (A-98-44)
>
> Conduct an audit of all Code of Federal Regulations Part 121 supplemental cargo operators to ensure that proper weight and balance documents are being used, that the forms are based on manufacturer's data or other approved data applicable to the airplane being operated, and that FAA principal inspectors confirm that the data are entered correctly on the forms. (A-98-45)
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> Require carriers operating under 14 Code of Federal Regulations Part 121 to develop and use loading checklists to positively verify that all loading steps have

been accomplished for each loaded position on the airplane and that the condition, weight, and sequencing of each pallet is correct. (A-98-46)

Require training for cargo handling personnel and develop advisory material for carriers operating under 14 Code of Federal Regulations Part 121 and principal operations inspectors that addresses curriculum content that includes but is not limited to, weight and balance, cargo handling, cargo restraint, and hazards of misloading and require all operators to provide initial and recurrent training for cargo handling personnel consistent with this guidance. (A-98-47)

Review the cargo loading procedures of carriers operating under 14 Code of Federal Regulations Part 121 to ensure that flightcrew requirements for loading oversight are consistent with the loading procedures in use. (A-98-48)

Evaluate the benefit of the STAN (Sum Total Aft and Nose) and similar systems and require, if warranted, the installation of a system that displays airplane weight and balance and gross weight in the cockpit of transport-category cargo airplanes. (A-98-49)

Require all principal inspectors assigned to 14 Code of Federal Regulations Part 121 cargo air carriers to observe, as part of their annual work program requirements, the complete loading operation including cargo weighing, weight and balance compliance, flight following, and dispatch of an airplane. (A-98-50)

Review its national aviation safety inspection program and regional aviation safety inspection program inspection procedures to determine why inspections preceding these accidents failed to identify systemic safety problems at ValuJet and Fine Air and, based on the findings of this review, modify these inspection procedures to ensure that such systemic indicators are identified and corrected before they result in an accident. (A-98-51)

Evaluate the surveillance programs to ensure that budget and personnel resources are sufficient and used effectively to maintain adequate oversight of the operation and maintenance of both passenger and cargo carriers, irrespective of size. (A-98-52)

Require an immediate readout of all 11-parameter retrofitted flight data recorders (FDRs) to ensure that all mandatory parameters are being recorded properly; that the FDR system documentation is in compliance with the range, accuracy, resolution, and recording interval specified in 14 Code of Federal Regulations Part 121, Appendix B; and require that the readout be retained with each airplane's records. (A-98-53)

Require maintenance checks for all FDRs of aircraft operated under 14 Code of Federal Regulations Parts 121, 129, 125, and 135 every 12 months or after any maintenance affecting the performance of the FDR system, until the effectiveness of the proposed advisory circular and new FAA inspector guidance on continuing FDR airworthiness (maintenance and inspections) is proven; further, these checks should require air carriers to attach to the maintenance job card records a computer printout, or equivalent document, showing recorded data, verifying that the parameters were functioning properly during the FDR maintenance check and require that this document be part of the permanent reporting and recordkeeping maintenance system. (A-98-54)

Provide FAA principal avionics inspectors with training that addresses the unique and complex characteristics of flight data recorder systems. (A-98-55)

Create a national certification team of flight data recorder (FDR) system specialists to approve all supplemental type certificate changes to FDR systems. (A-98-56)

Direct the principal maintenance inspector assigned to Fine Air to reexamine the airline's continuing analysis and surveillance program and take action, if necessary, to ensure that repetitive maintenance discrepancies are being identified and corrected. (A-98-57)

Amend 14 Code of Federal Regulations Part 121.563 to specifically require that all discrepancies be logged when they occur and be resolved before departure through repair or deferral in consultation with (the certificate holder's or contracted) maintenance personnel. (A-98-58)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: July 21, 1998

In reply to refer to: A-98-59 through -61

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

Since 1983, the National Transportation Safety Board has investigated 145 accidents involving aerial advertising/banner towing. Forty-five of the accidents (31 percent) resulted in 37 fatalities and 11 serious injuries. A recent review of the accidents by the Safety Board indicated that a majority of the accidents were associated with one or more of the following critical flight phases, circumstances, or events: the banner pickup maneuver, entangled or snarled banner tow lines, and loss of engine power.

Banner Pickup Maneuver (63 accidents)

The banner pickup maneuver is a critical low-level maneuver performed about 20 feet above the ground in which, while trailing a grapple hook, the pilot flies above and between two upright poles about 15 to 20 feet apart. The pilot's objective is to engage the banner tow loop (suspended between the poles) by applying full power and abruptly pitching the airplane upward just before arriving at the pickup poles. The banner, laid out on the ground, is connected to a tow line about 250 feet long. To lift the banner into the air and to avoid dragging it along the ground, the pilot exchanges speed energy for altitude, attempting to gain as much altitude as possible before moving the banner. The airspeed decreases rapidly during the maneuver because of the airplane's nose-high pitch attitude. As the airspeed approaches the best angle-of-climb airspeed, the pilot must begin lowering the nose of the airplane to avoid a stall. However, for a variety of reasons, including inadequate pickup airspeed, excessive pitch attitude, and delay in reducing pitch attitude, about 50 percent of the accidents involving this maneuver result in a stall or a stall/spin and a subsequent collision with the ground. The fundamental problem is largely operational, involving banner pilot training, experience, and competence issues.

Entangled or Snarled Banner Tow Lines (32 accidents)

A grapple hook and cable assembly, the device used to engage the tow line during the banner pickup, is about 30 feet long. One end of the cable is attached to the tow release mechanism on the tail of the airplane adjacent to the rudder control horns. Typically, the grapple hook and cable are brought forward along the side of the fuselage and through the cockpit window; they are stowed in the cockpit until the airplane is airborne and the pilot is ready to pick up the banner. The pilot then drops the hook and cable, allowing it to trail into position below and behind the airplane. However, if the hook and cable pass too closely to the side of the fuselage, the assembly sometimes becomes entangled or wrapped around the rudder control horns and disables the tow release mechanism. If the banner is picked up with the cable entangled in this manner, it causes significant loading and deflection of the rudder control horns and rudder, which leads the airplane to yaw severely. About 80 percent of the accidents involving entangled banner tow lines result in an in-flight loss of control and a subsequent collision with the ground or a loss of airplane performance and control during landing.

Loss of Engine Power (31 accidents)

A partial or total loss of engine power can occur because of fuel exhaustion, fuel starvation, fuel contamination, inadequate maintenance, or mechanical failure. Because typical banner towing operations are performed at relatively low altitudes, the loss of engine power usually allows the pilot little time to initiate emergency procedures, release the banner tow line, or position the airplane for a successful forced landing. About 40 percent of the accidents precipitated by loss of engine power involved in-flight collisions with objects/terrain; 20 percent involved an in-flight loss of control. The airplane was ditched (landed in the water) in 13 of the accidents.

Banner towing operations are conducted under a certificate of waiver or authorization issued by the Federal Aviation Administration (FAA) in accordance with Title 14 Code of Federal Regulations (CFR) 91.311, "Towing-Other Than Gliders." The respective FAA flight standards district office (FSDO) issuing the banner towing certificate may append special provisions to the certificate in the interest of safety if the operator uses nonstandard equipment or for other reasons such as geographical considerations, pilot limitations, air traffic control limitations, or weather conditions. The Safety Board is aware of one FSDO that appends special provisions concerning banner pilot minimal training and safety equipment to all banner towing certificates.

Operators who hold a certificate of waiver or authorization have the responsibility to train each new pilot in banner tow operations and in the special provisions of the waiver. However, there are no specific regulatory requirements or other guidelines, such as an FAA advisory circular (AC), that uniquely address banner tow training or operations. The amount of training given and the training syllabus used, if any, is largely at the discretion of the individual operators. The FAA requires that the new banner tow pilots demonstrate proficiency by performing one banner pickup and drop with the maximum number of letters (panels) to be used by the certificate holder. However, repeated accidents involving inadequate pilot performance (failure to maintain airspeed, misjudgment of clearance, etc.) during the banner pickup maneuver indicate a lack of adequate training and proficiency in performing the maneuver under both normal and abnormal (entangled banner) circumstances.

Although very few formal or structured banner towing training courses are available, the Safety Board is aware of one course[1] that has been approved by the FAA under 14 CFR Part 141, "Pilot Schools." The curriculum, which contains comprehensive ground and flight training designed to enable pilots to safely tow commercial banners, is described as follows:

> Complete ground school on all related subjects, including FARs, waiver requirements, banner assembly, pre-and-post-flight of aircraft, banner tow equipment and banners, repair to banners and equipment, communications, emergency procedures, ground crew coordination and marketing. Flight training includes pick-up and drop procedures, in-flight emergencies involving banner towing, normal procedures, and abnormal procedures. Includes actual banner towing missions and ample practice banner pick-ups and drops.

The lesson syllabus includes repeated low passes (over the banner pickup zone) with emphasis on altitude and airspeed control, maximum performance maneuvers, failure of the tow release mechanism, loss of rudder control, repeated pickup and drop of the banner tow line (with and without the banner attached), and loss of engine power with the banner attached. Because of the history of accidents involving banner towing, which indicates that current training procedures are inadequate, the Safety Board believes that the FAA should require banner tow operators to train new banner tow pilots using an FAA-approved banner tow training syllabus, similar to the one above.

The Safety Board also believes that the FAA should issue a comprehensive aerial advertising/banner towing AC containing detailed information concerning FAA regulations and requirements; banner towing equipment and flight operations, including tow hitch and release mechanisms; banner assembly size and weight considerations, layout, and banner aircraft performance limitations; flight training guidelines/criteria for safe and efficient performance of the banner pickup maneuver and other phases of banner towing operations; fuel management; in-flight emergencies, including entangled/snarled banner tow lines and loss of engine power; and aircraft, engine, and banner equipment maintenance requirements.

The hazards caused by banner tow lines becoming entangled with the rudder control horns and/or tow release mechanism can be avoided through use of simple mechanical devices.[2] For example, for tail wheel airplanes with horizontal stabilizer support wires, a spring-action clip can be fastened to the lower stabilizer wire near the point where it joins the outboard bottom surface of the stabilizer. The tow cable may then be routed from the tow release mechanism outboard to the spring clip and then forward to the cockpit, ensuring that the cable is held away from the fuselage when the grapple hook and cable assembly are dropped. The weight of the hook and cable then pulls the cable away from the spring clip, and the cable trails normally behind and below the airplane.

A second device consists of a guard attached to the bottom of the fuselage projecting outward and aft from either side of the fuselage. This can be fabricated from a steel rod 1/4 to 3/8 inch in diameter bent at the center to form a "V." A small plate welded to the rod at the bend

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[1] *Banner Tow Training*, Kaimana Aviation, Inc., Ponca City, Oklahoma 74601.

[2] Refer to *Instruction Booklet for Gasser Banner Equipment*, Gasser Banner, Inc., Nashville, Tennessee 37217.

serves as a base for attachment to the fuselage. The length and spread of the "V" is designed so that a tow cable sliding along the side of the fuselage toward the rear would be deflected outward around the rudder control horns and clear of the steering arms and springs.

Because these devices can prevent banner tow lines from becoming entangled with the rudder control horns and/or tow release mechanisms, the Safety Board believes that the FAA should require the installation of a mechanical safety device on the tails of tow airplanes such as a V-bar guard or stabilizer wire spring clip, designed to prevent entanglement of the banner grapple hook/cable assembly with the airplane's rudder control horns and/or tow release mechanism.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require banner tow operators to train new banner tow pilots using an FAA-approved banner tow training syllabus. The training syllabus should include repeated low passes (over the banner pickup zone) with emphasis on altitude and airspeed control, maximum performance maneuvers, failure of the tow release mechanism, loss of rudder control, repeated pickup and drop of the banner tow line (with and without the banner attached), and loss of engine power with the banner attached. (A-98-59)
>
> Issue a comprehensive aerial advertising/banner towing advisory circular containing detailed information about FAA regulations and requirements; banner towing equipment and flight operations, including tow hitch and release mechanism, banner assembly size and weight considerations layout, and banner aircraft performance limitations; flight training guidelines/criteria for safe and efficient performance of the banner pickup maneuver and other critical phases of banner towing operations; fuel management; in-flight emergencies, including entangled/snarled banner tow lines and loss of engine power; and aircraft, engine, and banner equipment maintenance requirements. (A-98-60)
>
> Require the installation of a mechanical safety device on the tails of tow airplanes such as a V-bar guard or stabilizer wire spring clip, designed to prevent entanglement of the banner grapple hook/cable assembly with the airplane's rudder control horns and/or tow release mechanism. (A-98-61)

Chairman HALL and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations. Vice Chairman FRANCIS concurred with recommendation A-98-60, but disapproved recommendations A-98-59 and -61.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: July 31, 1998

In reply refer to: A-98-62 through 64

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On February 17, 1998, the right main landing gear (MLG) of a Boeing 757-200 (757) airplane, operated by Canada 3000 on an intended passenger charter flight from Brussels, Belgium, to Montreal, Canada, collapsed while the airplane was taxiing for takeoff at Brussels International Airport. None of the occupants were injured and the airplane sustained minor damage. The airplane had accumulated 11,450 cycles and 42,196 hours in 8 years and 9 months of service.

The National Transportation Safety Board is participating in the Belgian Civil Aviation Administration's investigation of the incident, in accordance with the provisions of Annex 13 to the Convention on International Civil Aviation. Postincident examination of the right MLG revealed a circumferential fracture on its truck beam, which had broken into two large sections. The examination of the fracture surfaces revealed intergranular stress corrosion cracking (SCC) emanating from corrosion pits on the lower inside diameter of the truck beam. Examination of the inside surface of the truck beam revealed multiple localized areas where the primer painted on the inside surface had deteriorated, bubbled-up, or was missing.

The 757 MLG is a conventional, four-wheel, dual-tandem landing gear that has a metering pin orifice shock strut (see figure 1). The gear has four support points: the forward trunnion, the aft trunnion, the drag brace, and the side strut. The shock strut outer cylinder of the MLG assembly transfers operational loads from the truck assembly to the four support points. The assembly consists of a truck beam, axles, wheels and tires, brake rods, and a protective shield. The truck beam is the primary supporting member of the truck assembly. It pivots on the lower end of the shock strut outer cylinder.

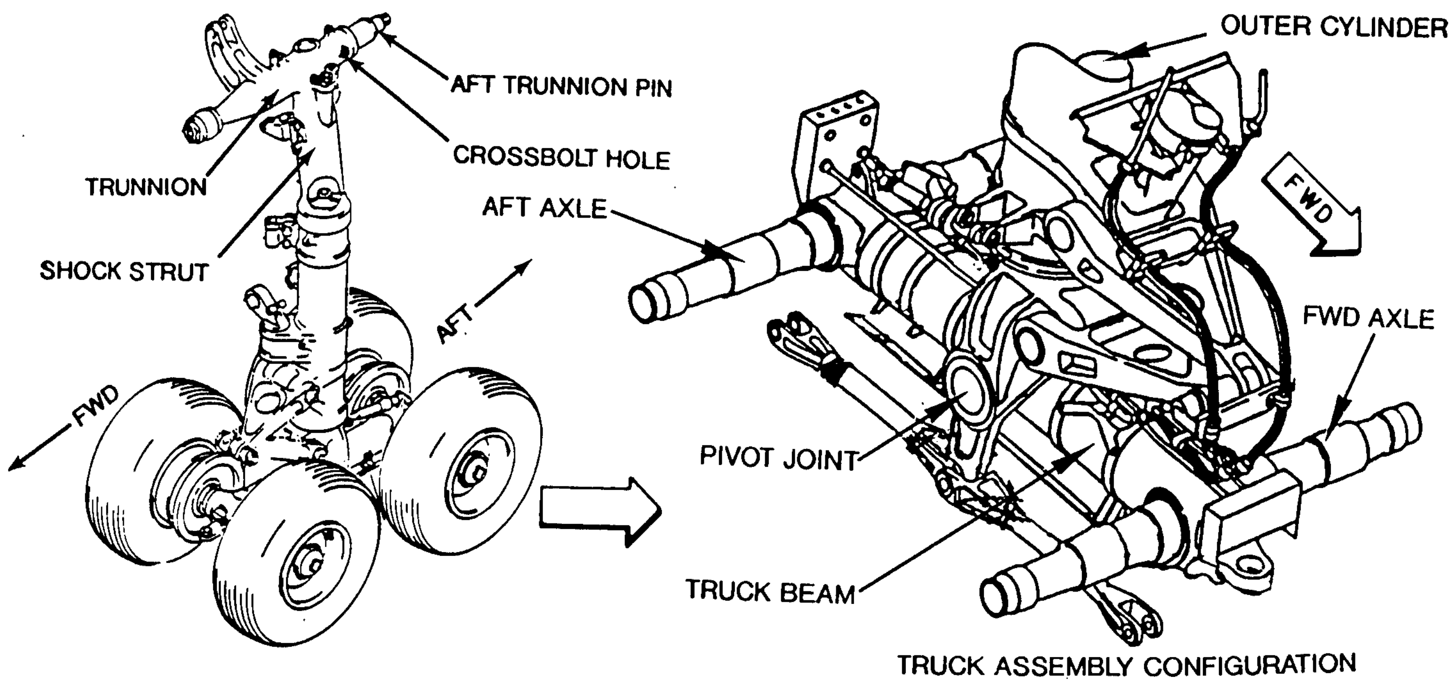

Figure 1. Boeing 757 Main Landing Gear Assembly

The truck beam is a hollow cylinder made from 4340M steel. The inner surface has three primary means of corrosion protection: cadmium-titanium electroplating; Boeing Material Specification BMS10-11 type 1 primer; and MIL-C-11796 Class 1 corrosion-inhibiting compound (CIC), also called Cosmoline. This CIC is applied in a hot liquid form and coats the inner surface of the truck beam with a uniform layer. Any moisture in the truck beam is drained through an opening at the aft end of the cylindrical truck beam section by gravity during truck tilt during takeoff.

The Safety Board's materials laboratory examined the right MLG truck beam and found three anomalies: missing primer, missing CIC, and a plugged drainage opening. About 75 percent of the inner surface of the truck beam was missing CIC, exposing the primer. There were localized spots of corrosion and exposed bare metal where the primer was missing. The primer was missing primarily on the bottom inner surface of the truck beam. In this area, some remaining primer had bubbled up and could easily be scraped off. Both ends of the truck beam contained approximately 2-inch diameter globules of CIC and grease. These globules and a dirt/grease mixture had clogged the truck beam's drainage opening.

The examination of the fracture surfaces disclosed a 0.9-inch wide region that showed characteristics of SCC. The primer was missing on the inner surface of the truck beam in the SCC area. Scanning electron microscope examination of the 0.9-inch wide SCC fracture region disclosed intergranular features, typical of SCC in 4340M steel, that emanated from three corrosion pits on the inner diameter surface. These corrosion pits measured no more than 0.01 inch deep by 0.01 inch diameter. The rest of the fracture area exhibited river pattern features characteristic of overstress.

Examination of the left MLG of the incident airplane at the overhaul facility revealed large globules of grease and CIC clogging the truck beam drainage opening similar to that found in the right MLG. The CIC had separated from the inner surface and there were patches of corrosion and areas where the primer was missing. The surface corrosion on the inner surface of the left MLG truck beam was more extensive than that found on the right MLG.

Boeing records indicate no other 757 MLG truck beam failures from SCC. Following this incident, the Safety Board contacted various 757 MLG overhaul facilities and was informed that typically 757 MLGs are inspected and overhauled after 8 to 10 years of service. Boeing's Maintenance Planning Document[1] for the 757 recommends the disassembly/restoration of the MLG between 12,000 and 18,000 cycles, or 10 years, whichever occurs first. The overhaul facilities informed the Safety Board that at overhaul, almost all 757 MLG truck beam inner surfaces exhibit patches of corrosion, but the primer and CIC are normally present. The overhaul facilities reported that globules of grease and CIC had not been found in any MLG truck beam that they had overhauled. The overhaul facilities reported that the truck beam drainage opening was found clogged in some MLGs that had been brought in for overhaul, but Boeing has informed the Safety Board that there have been a few isolated cases in which the CIC has separated from the truck beam inner surface and the primer has remained intact.

According to Boeing, if the CIC or primer separates from the inner surface, the corrosion protection capability is reduced. Also, if the gravity drain opening is clogged, the truck beam will retain ingested moisture creating an environment conducive to corrosion and SCC. The 757 maintenance manual does not specify a way to determine the condition of the corrosion protection layers (i.e., CIC and primer) or the gravity drainage opening of the MLG truck beam before overhaul. Because moisture is one of the primary causes of corrosion and can easily be ingested into the truck beam, it is important to eliminate it by preventing the drain opening from becoming blocked. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require operators of 757s to conduct periodic inspections of the MLG truck beam to ensure that the drainage opening at the aft end of the beam is unobstructed.

The balling up of the CIC and the loss of the primer from the interior surface of the truck beam resulted in the corrosion protection deteriorating over much of the surface of the beam, including the area where the stress corrosion cracking initiated. The presence of moisture and aggressive contaminants trapped within the beam by blockage of the drainage opening probably accelerated the deterioration of the corrosion protection and created an environment that led to the initiation of the stress corrosion cracking. A periodic visual inspection of the truck beam inner surface is important to detect the condition of the CIC and primer to minimize the possibility of corrosion or SCC in the beam. Also, to ensure detection of corrosion and cracking on the inner surface of the 757 truck beam, a nondestructive

[1] The Boeing Maintenance Planning Document provides general guidance to airlines in the formulation and establishment of individual maintenance programs.

inspection (NDI) technique should be developed and implemented. The Safety Board is aware that Boeing and other operators have developed NDI techniques to detect corrosion and cracks in the trunnion bore of the 767 MLG, and the FAA has mandated the inspection.[2] A similar technique could be developed to detect corrosion and cracks on the inner surface of 757 truck beams. Because no inspection methods currently exist to detect the condition of the CIC and primer or corrosion and cracks in the truck beam, the Safety Board believes that the FAA should develop and require the periodic use of visual and NDI techniques to evaluate the condition of CIC and primer and to detect corrosion and cracks on the inner surface of the 757 MLG truck beam.

Boeing has not yet completed its analysis of samples of the CIC and primer from the Canada 3000 incident airplane MLG truck beam to determine the reasons for reduction in its corrosion protection capabilities. It is important that the FAA monitor the progress of that analysis and take appropriate actions accordingly. Therefore, the Safety Board believes that the FAA should monitor Boeing's testing and analysis of the Canada 3000 MLG truck beam CIC and primer and, after the reasons for the reduction in its corrosion protection capabilities are determined, take corrective action to ensure that 757 MLG truck beams have adequate corrosion protection.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require operators of Boeing 757s to conduct periodic inspections of the main landing gear truck beam to ensure that the drainage opening at the aft end of the beam is unobstructed. (A-98-62)
>
> Develop and require the periodic use of visual and nondestructive inspection techniques to evaluate the condition of corrosion inhibiting compound and primer and to detect corrosion and cracks on the inner surface of the Boeing 757 main landing gear truck beam. (A-98-63)
>
> Monitor the Boeing Commercial Airplane Group's testing and analysis of the Canada 3000 main landing gear truck beam corrosion inhibiting compound and primer and, after the reasons for the reduction in its corrosion protection capabilities are determined, take corrective action to ensure that Boeing 757 main landing gear truck beams have adequate corrosion protection. (A-98-64)

[2] See Safety Board recommendations A-95-101 and -102, issued on October 27, 1995, which addressed a Boeing 767 right MLG trunnion failure in Hamburg, Germany.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 12, 1998

In reply refer to: A-98-65 through -66

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On January 5, 1997, a Fairchild Aircraft SA227-AC, N165SW, equipped with two AlliedSignal (formerly Garrett Turbine Engine Company) TPE331-11U-612 turbopropeller engines, experienced an ice-induced dual-engine flameout.[1] The flight had originated at Long Beach, California, as an on-demand Title 14 Code of Federal Regulations Part 135 air taxi passenger flight to Grand Canyon Airport, Tusayan, Arizona. The weather at Grand Canyon Airport had deteriorated below the allowable landing minimums, requiring the pilot to execute a missed approach. The airplane was subsequently diverted to the Bullhead City Airport, Bullhead, Arizona, and was on final approach when both engines flamed out. The pilots were unable to restart the engines, so they executed a forced landing 1.5 miles south of the Bullhead City Airport, which caused substantial damage to the airplane. The two pilots sustained minor injuries; none of the 19 passengers were injured.

Weather data for the Grand Canyon and Bullhead City airports indicated that the airplane had flown in moist air with temperatures at minus 5°C. The pilots stated that they observed ice accumulating on the airplane wings while flying en route to the Grand Canyon Airport and they had cycled the deice boots[2] to shed the ice. However, they stated that they did not activate the engine's override ignition system or the engine inlet heat as required by procedures in the airplane's flight manual (AFM) for flight-in-icing conditions. The Safety Board concluded that the dual-engine flameout was caused by ice ingestion and by the pilots' failure to select engine override ignition as required when flying in icing conditions. (See enclosed accident brief.)

[1] An ice-induced flameout is the unintentional termination of combustion that occurs when ice or slush momentarily interrupts airflow to the engine causing an over-rich fuel/air mixture within the engine's combustion chamber.

[2] Deice boots are inflatable rubber tubes that are attached along the wing's leading edge. After a nominal amount of ice accumulates, the pilot inflates the boots, which breaks away the ice from the leading edge of the wing.

On April 1, 1993, a Fairchild Aircraft SA227-TT, N500AK, equipped with two AlliedSignal TPE331-10U-513G turbopropeller engines, experienced a dual-engine flameout and crashed while the pilot was performing an instrument landing system approach to the Tri-City Regional Airport, Blountville, Tennessee. The airplane was destroyed, and all four people on board were killed.

Weather at the time of the accident was reported as light rain, fog, temperature 7°C, dew point 5°C, and a visibility of 6 miles. Additionally, several pilots landing at the Tri-City Airport about the time of the accident reported light-to-moderate rime icing between 5,000 and 14,000 feet.

During the Safety Board's investigation of this accident, it was discovered that neither engine was rotating and the propellers were feathered at impact. Additionally, examination of the pilot's annunciator panel revealed that both engine and propeller heat "ON" captions were illuminated at impact, indicating that the pilot had turned these systems on, most likely when he became aware of the ice accumulation. The ignition switch panel was destroyed by fire; therefore, the positions of the ignition switches could not be determined. The Safety Board concluded that both engines stopped operating before impact because of simultaneous flameouts or flameouts in rapid succession caused by ice ingestion and that the flameouts most likely occurred because the pilot did not follow the approved procedures for icing conditions as specified in the AFM. (See enclosed accident brief.) The feathered propellers indicated that the pilot recognized the dual-engine flameout situation and was attempting to restart the engines. The AFM provides a single-engine restart procedure but does not provide a dual-engine restart procedure. The Safety Board concludes that AFM procedures are necessary to provide pilots proper guidance if a dual-engine flameout occurs.

Conditions for engine and airframe ice formation are ideal when the outside air temperature is approximately 10°C or below with visible moisture (with a temperature/dew point spread of 3°C or greater). However, engine inlet duct icing can occur without airframe icing at ambient temperatures above freezing when intake air is drawn into the engine rather than being rammed in, such as when an airplane is climbing at low speed and high power. The suction reduces the static air pressure within the inlet duct, causing the incoming air to expand and cool to subfreezing temperatures. Under those conditions, with outside air temperatures well above freezing, ingested water vapor will freeze and be deposited in the engine inlet duct. The pilot may not recognize the potential for engine inlet icing conditions and may not anticipate the need to take specific actions to prevent an engine flameout.

Most TPE331-powered airplanes have a pilot-activated engine anti-ice system to prevent the accumulation of ice in the engine inlet duct. When selected by the pilot, the anti-ice system directs hot engine bleed air to the engine inlet lip to prevent ice formation in the engine inlet. This system is designed to be activated before ice accumulation; it is not intended as a deicing system. Activation of the anti-ice system after ice has accumulated can cause pieces of ice to shed from the inlet lip and cause an engine flameout. As an added flameout protection, some TPE331-powered Fairchild airplanes incorporate an "automatic" ignition system (see right side of figure 1) that can detect a flameout and automatically activate the ignition system. This system is not truly automatic because the pilot must first select an ignition mode using a manually selectable three-position switch. Flameouts can be detected by the decay in certain engine parameters, such as engine revolutions per minute or torque. The automatic ignition system can relight the engine without pilot action or awareness of any engine or airplane performance changes if the ignition mode switch is in the automatic position.

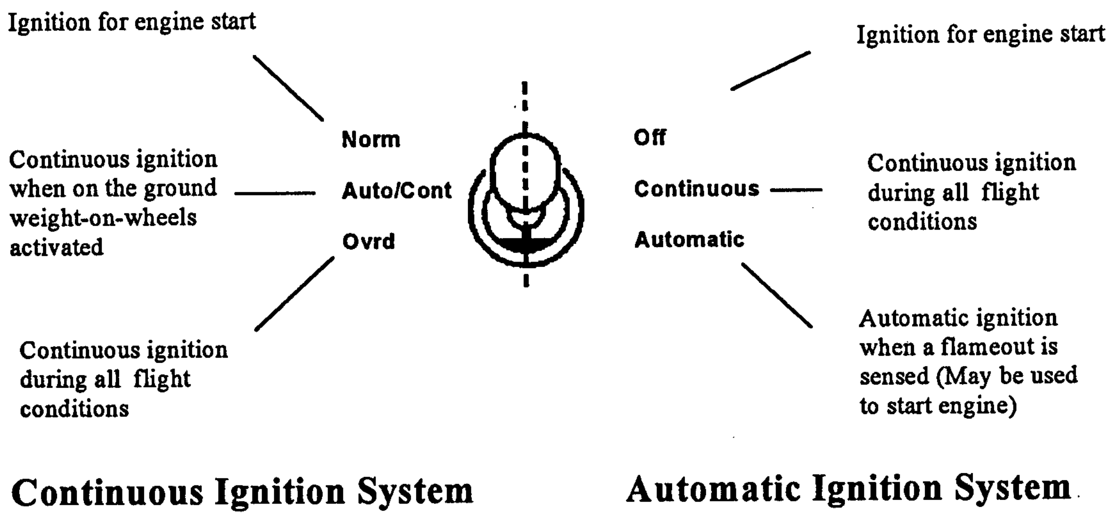

Figure 1. Typical Ignition Switch Position Labeling in TPE331-powered Airplanes

The Fairchild Aircraft ignition system installed in the Bullhead City and Blountville accident airplanes did not incorporate the automatic ignition system but a "continuous" ignition system (see left side of figure 1), which provides continuous ignition in flight when the pilot selects the "override" mode using a similar three-position switch. The Fairchild SA227-AC and SA227-TT airplane AFMs state that in advance of intentionally flying into icing conditions and heavy rain, the pilot should select engine and propeller heat and override ignition. The procedures for inadvertent flight-into-icing conditions state that after discovering ice accumulation, the pilot should select "override" ignition, then engine and propeller heat for one engine (to ensure that the engine is operating satisfactorily), and then engine and propeller heat for the other engine.

To address reports of ice-induced dual-engine flameouts in TPE331 engines, from 1982 through 1986, Garrett introduced two improved ignition system exciters,[3] and also issued various

[3] Garrett has introduced improvements that have increased the exciter duty cycle from 5 minutes to 1 hour to unlimited. All three of these exciter systems are still in use in TPE331-powered airplanes in the United States. The exciter serves to convert either AC or DC low-voltage power to a high-voltage potential for delivery to the igniter plug.

operating information letters[4] to emphasize the proper use of engine anti-ice and to provide additional information on the proper use of engine ignition systems in icing conditions. Additionally, on July 8, 1985, following a January 8, 1985, dual-engine flameout incident in Covington, Kentucky, the Safety Board issued Safety Recommendations A-85-50 through -52 to the Federal Aviation Administration (FAA) to require that Fairchild relabel the ignition switch positions on SA226 and SA227 airplanes to remove any ambiguity with regard to the ignition switch position, to issue an air carrier operations bulletin (ACOB) to advise operators of the appropriate use of the continuous ignition mode, and to require that Fairchild revise the SA226 and SA227 AFMs to include a warning to place the engine ignition system in the continuous mode during flight-into-icing conditions.

On December 15, 1986, the FAA responded to the Safety Board's recommendations by issuing Airworthiness Directives (ADs) 86-24-11 and 86-25-04, which required revision of Fairchild Aircraft SA226 and SA227 AFMs to include the new warnings and procedures for flight-into-icing conditions, and issuing an ACOB with procedures to prevent engine flameout during and after flight into heavy precipitation or icing conditions, but did not relable the switch positions. The Safety Board classified the recommendation to relabel the switch positions "Closed—Acceptable Alternate Action" because it believed the AFM changes regarding engine heat and continuous ignition eliminated the ambiguity of when to use each ignition mode.

The FAA also issued several ADs for other TPE331-powered airplanes, such as those manufactured by Beech, Dornier, Gulfstream, Mitsubishi, British Aerospace, and Pilatus Britten-Norman.[5] The ADs addressed flight limitations, engine ignition systems, engine flameout protection, placards, increased duty-cycle exciter units, automatic ignition systems, and changes to the AFMs.

The Safety Board is aware of 25 reported incidents of ice-induced engine flameouts of TPE331-powered airplanes since 1974. Many of these were dual-engine flameouts. Despite changes mandated by the ADs, the Bullhead City and the Blountville accidents show that these improvements do not prevent all ice-induced flameouts.

The accident data show that pilots may fail to recognize icing conditions and to take appropriate action to prevent ice-induced engine failures. Pilots can easily misinterpret icing conditions when the temperature is well above freezing, especially at night when they may be unable to observe ice formations. The data show that many ice-induced flameouts occur during approach and landing, which are periods of high crew workload. In all of these circumstances it is difficult for the pilot to recognize icing conditions and then to manually select the appropriate ignition switch position. The Safety Board is concerned that the current ignition system designs

[4] On April 30, 1985, Garrett issued Operating Information Letter OI 331-11. After April 30, 1985, AlliedSignal reissued Operating Information Letter OI 331-11R1 in February 1988, OI 331-11R2 in November 1993, and OI 331-11R3 in April 1997. Additionally, on November 15, 1994, AlliedSignal issued Pilot Advisory Letter 331-04R1 regarding ice-induced dual-engine flameouts.

[5] Beech-AD 86-24-09, December 15, 1986; Dornier-AD 96-09-14, June 11, 1996; Gulfstream (Aero Commander)-AD 87-24-07R1, February 9, 1988; Mitsubishi-AD 84-12-04, AD 86-26-02, AD 96-25-02, dated June 29, 1984, December 31, 1986, December 12, 1996, respectively; British Aerospace-AD 86-24-10, December 15, 1986; Pilatus Britten-Norman-AD 91-05-09, March 25, 1991.

in TPE331-powered airplanes still leave those airplanes susceptible to ice-induced engine flameouts. Therefore, the Safety Board believes that the FAA should require that all TPE331-powered airplanes be equipped with an engine ignition system that is activated automatically (without pilot input) following an engine flameout. Because no dual engine flameout procedures are in the AFMs and many of the 25 reported ice-induced flameouts were dual-engine, as an interim measure, until an automatically activated ignition system is installed, the Safety Board believes that the FAA should require that the AFMs or pilot's operating handbooks for all TPE331-powered airplanes be modified, if necessary, to incorporate dual-engine failure or flameout procedures.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require that all TPE331-powered airplanes be equipped with an engine ignition system that is activated automatically (without pilot input) following an engine flameout. (A-98-65)
>
> As an interim measure, until an automatically activated ignition system is installed, require that the airplane flight manuals or pilot's operating handbooks for all TPE331-powered airplanes be modified, if necessary, to incorporate dual-engine failure or flameout procedures. (A-98-66)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

Enclosures

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 03/16/1994

ATL93MA068
FILE NO. 470 04/01/93 BLOUNTVILLE,TN AIRCRAFT REG. NO. N500AK TIME (LOCAL) - 21:28 EST

MAKE/MODEL - Fairchild SA227-TT
ENGINE MAKE/MODEL - Garrett TPE331-10U513
AIRCRAFT DAMAGE - Destroyed
NUMBER OF ENGINES - 2

	FATAL	SERIOUS	MINOR/NONE
CREW	1	0	0
PASS	3	0	0

OPERATING CERTIFICATES - None
TYPE OF FLIGHT OPERATION - Executive/corporate
REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 91

LAST DEPARTURE POINT - KNOXVILLE,TN
DESTINATION - Same as Accident

AIRPORT PROXIMITY - Off airport/airstrip
AIRPORT NAME - TRI-CITY REGIONAL
RUNWAY IDENTIFICATION - 23
RUNWAY LENGTH/WIDTH (Feet) - 7999/ 150
RUNWAY SURFACE - Asphalt
RUNWAY SURFACE CONDITION - Dry

CONDITION OF LIGHT - Night (dark)

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - 3500 FT Broken
VISIBILITY - 0006.000 SM
WIND DIR/SPEED - 250 /013 KTS
TEMPERATURE (F) - 46
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 48

CERTIFICATES/RATINGS
Commercial, Airline transport
Single-engine land, Multiengine land
INSTRUMENT RATINGS
Airplane

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 19105
LAST 90 DAYS - Unk/Nr
TOTAL MAKE/MODEL - 235
TOTAL INSTRUMENT TIME - Unk/Nr

N500AK ENCOUNTERED ICING IN FLIGHT BEFORE START OF ILS APPROACH. RADAR DATA SHOWED THAT BEFORE REACHING OUTER MARKER, IT SLOWED IN A MANNER THAT WAS CONSISTENT WITH A POWER REDUCTION (OR PARTIAL LOSS OF POWER), THEN IT ENTERED A STEEP DESCENT & CRASHED. EXAMINATION REVEALED ENGINES WERE NOT OPERATING AT IMPACT & THAT PROPELLERS HAD BEEN FEATHERED. NO PREIMPACT PART FAILURE OR MALFUNCTION OF ENGINES, PROPELLERS OR ANTI-ICE SYSTEM WAS FOUND. THERE WAS EVIDENCE THAT ENGINE INLET ANTI-ICE ANNUNCIATOR LIGHTS & STABILITY AUGMENTATION SYSTEM (SAS) FAULT WARNING LIGHT WERE ILLUMINATED DURING IMPACT. THE ENGINE MANUFACTURER REPORTED THAT FLAMEOUTS HAD OCCURRED IN OTHER AIRCRAFT, DURING OR FOLLOWING OPERATION IN ICING CONDITIONS, SOMETIMES AFTER DESCENT INTO WARMER AIR. FLIGHT MANUAL NOTED THAT IF ICING WAS ENCOUNTERED WITH ANTI-ICE SYSTEM OFF, SELECT CONTINUOUS IGNITION & THEN SELECT ENGINE & PROPELLER HEAT (1 ENGINE AT A TIME, ENSURING FIRST ENGINE WAS OPERATING SATISFACTORILY BEFORE SELECTING SECOND ENGINE) & ENGAGE SAS HEAT.

ATL93MA068
FILE NO. 470   04/01/93   BLOUNTVILLE,TN   AIRCRAFT REG. NO. N500AK   TIME (LOCAL) - 21:28 EST

Occurrence# 1   IN-FLIGHT ENCOUNTER WITH WEATHER
Phase of Operation   CRUISE

Findings
1. - LIGHT CONDITION - DARK NIGHT
2. - WEATHER CONDITION - ICING CONDITIONS
3. - NACELLE/PYLON - ICE

Occurrence# 2   LOSS OF ENGINE POWER(TOTAL) - NON-MECHANICAL
Phase of Operation   APPROACH - IAF TO FAF/OUTER MARKER (IFR)

Findings
4. - ALL ENGINES
5. - PROCEDURES/DIRECTIVES - NOT FOLLOWED - PILOT-IN-COMMAND
6. - ANTI-ICE/DEICE SYSTEM - IMPROPER USE OF - PILOT-IN-COMMAND

Occurrence# 3   LOSS OF CONTROL - IN FLIGHT
Phase of Operation   DESCENT - EMERGENCY

Findings
7. - AIRSPEED - NOT MAINTAINED - PILOT-IN-COMMAND
8. - STALL - INADVERTENT - PILOT-IN-COMMAND

Occurrence# 4   IN-FLIGHT COLLISION WITH TERRAIN/WATER
Phase of Operation   DESCENT - UNCONTROLLED

The National Transportation Safety Board determines that the probable cause(s) of this accident was:
FAILURE OF THE PILOT TO FOLLOW PROCEDURES CONCERNING USE OF THE ENGINE INLET ANTI-ICE SYSTEM AND/OR CONTINUOUS IGNITION WHILE OPERATING IN ICING CONDITIONS, WHICH RESULTED IN PROBABLE ICE INGESTION AND LOSS OF ENGINE POWER; AND THE PILOT'S FAILURE TO MAINTAIN SUFFICIENT AIRSPEED WHILE COPING WITH THE ENGINE PROBLEM, WHICH RESULTED IN A STALL. FACTORS RELATED TO THE ACCIDENT WERE: DARKNESS, ICING CONDITIONS, AND ENGINE INLET (NACELLE) ICE.

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 03/25/1998

LAX97FA082
FILE NO. 577 01/05/97 BULLHEAD CITY,AZ AIRCRAFT REG. NO. N165SW TIME (LOCAL) - 12:43 MST

MAKE/MODEL - Fairchild SA227-AC
ENGINE MAKE/MODEL - Garrett TPE331-11U612
AIRCRAFT DAMAGE - Destroyed
NUMBER OF ENGINES - 2

	FATAL	SERIOUS	MINOR/NONE
CREW	0	0	2
PASS	0	0	19

OPERATING CERTIFICATES - On-demand air taxi
NAME OF CARRIER - FNG AVIATION INC
TYPE OF FLIGHT OPERATION - Non-scheduled
- Domestic
- Passenger

REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 135

LAST DEPARTURE POINT - LONG BEACH,CA
DESTINATION - GRAND CANYON,AZ

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 0020.000 SM
WIND DIR/SPEED - 010 /007 KTS
TEMPERATURE (F) - 50
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 33

CERTIFICATES/RATINGS
Airline transport
Single-engine land, Multiengine land
INSTRUMENT RATINGS
Airplane

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 3200
LAST 90 DAYS - 50
TOTAL MAKE/MODEL - 300
TOTAL INSTRUMENT TIME - 250

After executing a missed approach at the Grand Canyon Airport, the pilots diverted to the Bullhead City Airport. The pilots reported that minimal icing conditions were encountered with about 1/8 inch of ice accumulating on the aircraft wings. The pilots stated they cycled the deice boots to shed ice. They did not observe ice on the propeller spinners, and they did not activate the engines' "override" ignition systems, as required by the airplane's flight manual. Use of "override" ignition was required for flight into visible moisture at or below +5 degrees Celsius (+41 degrees Fahrenheit) to prevent ice ingestion/flameouts. Subsequently, both engines flamed out as the airplane was on about a 3 mile final approach for landing with the landing gear and flaps extended. The aircraft was destroyed during an off-airport landing.

Brief of Accident (Continued)

LAX97FA082
FILE NO. 577 01/05/97 BULLHEAD CITY,AZ AIRCRAFT REG. NO. N165SW TIME (LOCAL) - 12:43 MST

Occurrence# 1 IN-FLIGHT ENCOUNTER WITH WEATHER
Phase of Operation CRUISE

Findings
1. - WEATHER CONDITION - ICING CONDITIONS
2. - AIRFRAME - ICE

Occurrence# 2 LOSS OF ENGINE POWER(TOTAL) - NON-MECHANICAL
Phase of Operation APPROACH

Findings
3. - ALL ENGINES
4. - IGNITION SYSTEM,AUTO RE-LIGHT SYSTEM - NOT INSTALLED
5. - AIRCRAFT/EQUIPMENT INADEQUATE
6. - IGNITION SYSTEM,IGNITER - NOT ACTIVATED
7. - CHECKLIST - NOT FOLLOWED - PILOT-IN-COMMAND
8. - MISCELLANEOUS,ENGINE - ICE INGESTION

Occurrence# 3 FORCED LANDING
Phase of Operation EMERGENCY DESCENT/LANDING

Occurrence# 4 IN-FLIGHT COLLISION WITH TERRAIN/WATER
Phase of Operation EMERGENCY LANDING

Findings
9. - TERRAIN CONDITION - NONE SUITABLE

The National Transportation Safety Board determines that the probable cause(s) of this accident was: failure of the pilot(s) to use "override" ignition as prescribed by checklist procedures during an encounter with icing conditions, which subsequently led to ice ingestion and dual engine flame-outs. Factors related to the accident were: the adverse weather (icing) conditions, the accumulation of airframe/engine ice, and lack of suitable terrain in the emergency landing area.

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: August 11, 1998

In reply refer to: A-98-67 through -70

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On September 6, 1997, a Saudi Arabian Airlines (Saudia) Boeing 737-200, powered by two Pratt & Whitney (P&W) JT8D-15 engines, experienced an uncommanded acceleration of the No. 2 (right) engine during takeoff roll at Najran, Saudi Arabia. The captain reported that he noticed that the exhaust gas temperature (EGT) overtemperature light for the No. 2 engine was illuminated during the takeoff roll at approximately 110 knots. The captain reduced thrust on the No. 2 engine, but the EGT indication remained at the maximum EGT limit. The takeoff was rejected and the thrust levers were retarded to idle; however, the No. 2 engine remained at a high power level. Further attempts to retard the power were unsuccessful and the airplane departed the left side of the runway, resulting in damage to the landing gear and separation of the No. 2 engine. Four of the 79 passengers sustained minor injuries during the evacuation, and the airplane was destroyed by a postcrash fire. The National Transportation Safety Board is participating in the Presidency of Civil Aviation of the Kingdom of Saudi Arabia's investigation in accordance with the provisions of Annex 13 to the Convention on International Civil Aviation.

The fuel pump and fuel control for the No. 2 engine were removed and later disassembled during an inspection. Included in the JT8D engine fuel pump assembly is a splined control shaft[1] that transmits the N_2[2] signal from the fuel pump to the fuel control. The control shaft is splined on one end where it mates with the fuel pump and on the opposite end where it mates with the fuel control. Although damage to the housing precluded a bench test of the fuel control, no wear of the mating splines between the fuel control and the control shaft was observed. However, the splines where the control shaft mates with the fuel pump were almost completely stripped. This damage allowed the splines of the fuel pump gear shaft to rotate past the splines of the control shaft.

[1] A shaft containing a set of integral keys, or teeth, that fit within corresponding grooves on a mating shaft or gear.
[2] Rotational speed of the high-pressure compressor. The N_2 signal is one of several inputs used by the fuel control to schedule fuel delivery.

Following a series of control shaft spline failures in the late 1970s attributed to misalignment of the control shaft, Argo-Tech Corporation, the manufacturer of JT8D fuel pumps, conducted tests on the fuel pump to determine the cause of the failures. The testing indicated that torque generated during operation of the pump was causing misalignment between the control shaft and the mating gear in the fuel pump, which was leading to premature wear of the control shaft splines. To address this problem, Argo-Tech issued Service Bulletin (SB) 73-34 on January 15, 1980. The SB specifies a 0.0036-inch lateral shift of the fuel pump's gear train to reduce control shaft spline wear problems (with no tolerance allowed). Records indicated that after installation of a new control shaft on the fuel pump from the Saudia airplane in 1993, the gear train was offset per the SB by an overhaul facility. However, postaccident measurement showed that the centerline shift of the gear train was 0.0030 inch, which is outside the allowable tolerance. The pump had been operated 3,237 hours since the SB modification.

The centerline shift recommended by SB 73-34 was established to reduce wear of the control shaft splines caused by misalignment resulting from normal operation. The SB is applicable to all JT8D-1 through -15 engines, which are installed on Boeing 727, 737-100/-200, and DC-9 series airplanes, but is not required. The SB action was incorporated as a production modification on all JT8D-17 engines and -200 engines. JT8D-17 engines are installed on some Boeing 727-200, 737-200, and DC-9-50 series airplanes. JT8D-200 engines are installed on advanced 727-200 and MD-80 series airplanes.

The Safety Board requested information from P&W and Boeing on incidents involving known or suspected[3] fuel pump control shaft failures on JT8D engines. P&W's database contained 39 incidents since 1980 in which JT8D control shaft malfunctions were involved or suspected. Of the 26 incidents reported by Boeing on 727, 737, and DC-9 airplanes, only 6 also appear on the P&W list. It is not known how many of the reported control shaft failures included pumps that had previously been modified per SB 73-34. However, the data provided by P&W include two incidents involving JT8D-17 engines, indicating that even fuel pumps with the SB modification incorporated during original production might be susceptible to control shaft spline wear.

Argo-Tech stated that it is aware of three confirmed fuel pump failures related to misalignment of the control shaft. Argo-Tech's database, which only dates back to 1993, also shows that four of the fuel pumps returned to its facilities contained excessive (90 to 100 percent) control shaft spline wear. It should be noted that at least 10 control shaft spline failures were reported in 1978 before the issuance of SB 73-34 and that the frequency of failure or excessive wear of the control shaft might be higher because of a lack of reporting.

The incidents involving the JT8D fuel pump malfunctions have occurred during takeoff, climb, cruise, descent, and approach flight segments. The Safety Board is aware of two U.S. incidents that have occurred since the Saudia accident. The most recent incident occurred on October 17, 1997, and involved a Delta Airlines Boeing 727, equipped with JT8D-15 engines, that experienced an uncommanded acceleration of the No. 1 engine during cruise flight. The

[3] Incidents in which an uncommanded thrust increase or a loss of power lever control occurred.

engine pressure ratio (EPR)[4] reportedly increased to 2.4 during the incident. The engine did not respond to throttle inputs, and the crew shut down the engine and diverted from their scheduled landing at New York's La Guardia Airport to New York's John F. Kennedy International Airport. Although no problems were found during a bench check of the engine's fuel pump and fuel control, subsequent examination of the fuel pump revealed wear of the control shaft splines. Delta indicated that SB 73-34 had been incorporated on their entire fleet of affected airplanes, including the incident airplane. However, the cause of the control shaft spline wear was not determined.

To further address wear of control shaft splines on JT8D fuel pumps, Argo-Tech issued SB 73-40 on May 4, 1998. The SB provides information to replace existing control shafts with a new control shaft made from through-hardened H11 steel. The new material offers better resistance to spline wear and should increase the control shaft's service life. The new control shaft was introduced into service under a controlled service use (CSU) program with two operators. As part of the CSU program, one of the control shafts was removed for examination after approximately 2,600 hours of operation; no wear of the shaft splines was detected.

P&W recommends that the fuel pump receive a bench test at 6,000 flight hours and an overhaul at 12,000 flight hours. Argo-Tech indicated that some airlines establish their own times between overhauls but that most fuel pumps are repaired or inspected only when they malfunction. Consequently, control shaft damage is not likely to be detected before failure.

The lack of required periodic fuel pump inspections and continuing problems related to control shaft spline wear indicate that action should be taken to ensure proper alignment and reduce wear of the fuel pump control shaft on all JT8D engines. Therefore, the Safety Board believes that the FAA should require that the fuel pumps on all P&W JT8D engines be modified in accordance with Argo-Tech SBs 73-34 and 73-40 to reduce operating misalignment of the control shaft and wear of the shaft splines. In addition, although incorporation of the SB modification should substantially address spline wear of the control shaft, recurrent inspections of the control shaft should also be required because of shaft wear or failure involving fuel pumps that had previously been modified per SB 73-34 and because long-term performance of the new control shaft has not been demonstrated. Pumps that have not been modified per the SBs should be subject to more frequent inspections. Accordingly, the Safety Board believes that the FAA should require recurrent inspections of the fuel pump control shaft on all P&W JT8D engines and replacement of control shafts exhibiting spline wear. Fuel pumps that have not been modified per SBs 73-34 and 73-40 should be subject to more frequent inspections.

The Safety Board is also concerned about a design feature incorporated on JT8D engine fuel controls called "zero speed protection." Zero speed protection occurs when the N_2 signal to the fuel control is lost, which results in an automatic shift in the fuel delivery schedule on the affected engine to approximately 90 to 95 percent takeoff power. When this occurs, engine thrust no longer responds to throttle movements. Fracture of the fuel pump control shaft or severe wear of the shaft splines will result in complete loss of the N_2 signal to the fuel control.

[4] The ratio of turbine exhaust pressure to fan inlet pressure.

According to P&W, the zero speed protection feature was incorporated to ensure that the engine would deliver high thrust during a critical flight phase following loss of the N_2 signal to the fuel control. Although the function of an automatic engine response such as this may be beneficial at takeoff, there are situations in which such a feature could lead to asymmetric thrust and directional control difficulties, including landing, taxi, and engine reverse operations. Directional control difficulties could also be exacerbated by contaminated runway surfaces or during any operation near other aircraft. In addition, because this type of engine response can occur whenever the engine is being started or operated, a potential hazard to personnel exists during operations at the gate or during maintenance activities.

A partial loss of the N_2 signal, which can occur if the control shaft splines are severely worn, can also trigger a shift in the fuel delivery schedule. A partial loss of the N_2 signal would be interpreted by the fuel control as a low-speed signal and would result in an increased fuel flow to regain the targeted N_2, which might also cause an exceedance of N_2, EPR, and EGT limits. The only method of reducing thrust after partial or complete loss of the N_2 signal is to shut off fuel to the affected engine through the fuel cutoff lever or the fire handle.

Identification of a failure in which zero speed protection engages might initially be difficult because the resulting thrust on the affected engine might differ little from the thrust requirements at the time of failure. However, when zero speed protection results in a large deviation from the desired thrust setting, quick and proper action by the flightcrew may be required to maintain directional control of the airplane. The Safety Board is concerned that flightcrews might not be properly informed about the zero speed protection feature and its effect on throttle authority.

A review of Saudia's 737 flight handbook, as well as flight manuals for the other affected airplanes, revealed no reference to the zero speed protection feature. Boeing has indicated that the zero speed protection feature is not addressed in its flight manuals for 727, 737, DC-9, and MD-80 airplanes. Following the Saudia accident, P&W issued an all operators wire on November 20, 1997, to recommend that all personnel operating JT8D-powered airplanes be informed about the zero speed protection feature and the corresponding ineffectiveness of the throttle. The only operator information issued by Boeing has been In-Service Activities Report (ISAR) 93-07, which was issued to 737 operators in 1993 following an in-flight event in which a fractured fuel pump shaft caused the loss of throttle lever control, and ISAR 97-24, which was issued to 737 operators in December 1997 following the Saudia accident. However, the ISARs offered only a minimal review of the circumstances of the accident and the zero speed protection feature. The Safety Board believes that the FAA should issue a flight standards information bulletin to the principal operations inspectors of all operators of 737-100/-200, 727, DC-9, and MD-80 airplanes informing the operators about the circumstances of the Saudia accident and the zero speed protection feature on P&W JT8D engines. The information should note the ineffectiveness of the throttle following engagement of zero speed protection.

P&W has further indicated that incorporation of the zero speed protection feature is not unique to the JT8D engine. The same philosophy is incorporated on JT3D and JT9D engine fuel controls and may also be incorporated on other in-service engine models. It is not known whether or to what extent this type of failure and engine response is addressed in crew training programs and flight manuals for airplanes equipped with other engine types. Therefore, the

Safety Board believes that the FAA, in conjunction with representatives from engine and airframe manufacturers and pilot groups, should address the issue of automatic engine response following the loss of inputs such as the N_2 signal by studying events in which uncommanded and uncontrollable engine power excursions have occurred and, based on the results of the study, make appropriate recommendations that address the following: 1) automatic engine response following the loss of certain inputs; and 2) crew operating and training issues related to uncommanded engine power excursions in which the throttle is ineffective.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require that the fuel pumps on all Pratt & Whitney JT8D engines be modified in accordance with Argo-Tech Service Bulletins 73-34 and 73-40 to reduce operating misalignment of the control shaft and wear of the shaft splines. (A-98-67)

> Require recurrent inspections of the fuel pump control shaft on all Pratt & Whitney JT8D engines and replacement of control shafts exhibiting spline wear. Fuel pumps that have not been modified per Argo-Tech Service Bulletins 73-34 and 73-40 should be subject to more frequent inspections. (A-98-68)

> Issue a flight standards information bulletin to the principal operations inspectors of all operators of Boeing 737-100/-200, 727, DC-9, and MD-80 airplanes informing the operators about the circumstances of the Saudi Arabian Airlines Boeing 737 accident and the zero speed protection feature on Pratt & Whitney JT8D engines. The information should note the ineffectiveness of the throttle following engagement of zero speed protection. (A-98-69)

> In conjunction with representatives from engine and airframe manufacturers and pilot groups, address the issue of automatic engine response following the loss of inputs such as the N_2 signal by studying events in which uncommanded and uncontrollable engine power excursions have occurred and, based on the results of the study, make appropriate recommendations that address the following: 1) automatic engine response following the loss of certain inputs; and 2) crew operating and training issues related to uncommanded engine power excursions in which the throttle is ineffective. (A-98-70)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 12, 1998

In reply refer to: A-98-71

Honorable Rodney E. Slater
Office of the Secretary
Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590

About 0554 eastern daylight time,[1] on September 5, 1996, a Douglas DC-10-10CF, N68055, operated by the Federal Express Corporation (FedEx) as flight 1406, made an emergency landing at Stewart International Airport, Newburgh, New York, after the flightcrew determined that there was smoke in the cabin cargo compartment. The flight was operating under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121 as a cargo flight from Memphis, Tennessee, to Boston, Massachusetts. Three crewmembers and two nonrevenue passengers were aboard the airplane. The captain and flight engineer sustained minor injuries while evacuating the airplane. The airplane was destroyed by fire after the landing.

The National Transportation Safety Board determined that the probable cause of this accident was an in-flight cargo fire of undetermined origin.[2]

Prohibited Items On Board the Accident Airplane

After the fire, investigators discovered a DNA synthesizer in cargo container 6R that contained small quantities of flammable liquids (including acetonitrile and tetrahydrafuran). These chemicals are classified by the Research and Special Programs Administration as hazardous materials and are therefore subject to Department of Transportation (DOT) requirements for packaging, labeling, and shipping documentation to accurately identify the hazardous nature of the shipment. However, because the synthesizer was not intended to be shipped with any hazardous materials, it was shipped as general freight and was not packaged or labeled in accordance with those requirements and was not accompanied by the required paperwork.

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[1] Unless otherwise indicated, all times are eastern daylight time, based on a 24-hour clock.

[2] National Transportation Safety Board. 1998. *In-Flight Fire/Emergency Landing, Federal Express Flight 1406, Douglas DC-10-10, N68055, Newburgh, New York, September 5, 1996.* Aircraft Accident Report NTSB/AAR-98/03. Washington, DC.

Several other items discovered on board the accident airplane might also have constituted shipments of undeclared hazardous materials. Seven aerosol cans and several plastic bottles containing acidic or alkaline liquids that could be corrosive, and two samples containing potentially flammable or combustible liquids were found in the cargo debris.[3] Although the original contents of the aerosol cans recovered from the accident aircraft could not be determined, aerosol cans, as pressurized containers with compressed gases, are regulated hazardous materials. The acidic and alkaline liquids in the plastic bottles were also likely subject to the DOT hazardous materials regulations as corrosive materials. Although the DOT hazardous materials regulations allow exceptions to packaging, marking, labeling, or shipping paper requirements, depending on the quantity and form of the material being shipped, these exceptions generally are not applicable when the item is being transported by air. Consequently, the aerosol cans and the containers of acidic liquid likely constituted undeclared shipments of hazardous materials. Although these items were ruled out as possible ignition sources of the fire, they again raise concerns about the prevalence of unknown hazardous materials being carried on board airplanes.

The ease with which prohibited materials can find their way onto commercial airplane flights was further highlighted by the discovery of several illegal shipments of marijuana on board the accident flight. Marijuana is not classified as a hazardous material for purposes of air transportation, and the marijuana found on board flight 1406 was not a factor in the accident. Further, the Safety Board notes that most undeclared shipments of hazardous materials are unintentional, although the shipment of marijuana is clearly a deliberate attempt to ship contraband material. Nonetheless, the Safety Board concludes that the presence of the aerosol cans, the containers of acidic liquid, as well as several packages of marijuana on board the accident flight illustrates that common carriers can be unaware of the true content of many of the packages they carry.

Federal and Industry Oversight

The shipment of undeclared and improperly packaged hazardous materials on board airplanes and the oversight by the Federal Aviation Administration (FAA) and air carriers to detect and identify such shipments was most recently addressed by the Safety Board in its report of the May 11, 1996, accident involving ValuJet Airlines. The Safety Board determined that the in-flight fire was initiated by the actuation of one or more chemical oxygen generators being improperly carried as cargo. These generators had not been identified as hazardous materials and were not properly packaged for transportation.

The Safety Board stated in the ValuJet report that the practices, procedures, and training of the personnel involved in the identification and handling of undeclared hazardous materials have remained inadequate. The Safety Board further noted that the ValuJet accident and incidents that occurred after that accident clearly demonstrate that the shipment of undeclared

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[3] The hazardous materials regulations define a corrosive material as "a liquid or solid that causes full thickness destruction of human skin at the site of contact within a specified period of time; [or a] liquid that has a severe corrosion rate on steel or aluminum." (49 CFR 173.136.) They also prescribe packaging standards based on the length of exposure of the corrosive material to human skin and the time after exposure for destruction of the skin to occur. (49 CFR 173.137.)

hazardous materials in air transportation is a serious problem that has not been adequately addressed. In the ValuJet report, the Safety Board further stated the following:

> [T]the FAA has initiated the evaluation requested by the Safety Board in Safety Recommendations A-96-25 and -26 of the practices and training provided by all air carriers for accepting passenger baggage and freight shipment (including COMAT [company materials]) and for identifying undeclared or unauthorized hazardous materials that are offered for transport and, based on this evaluation, to require air carriers to revise as necessary their practices and training in this area.
>
> Further, the FAA is developing a hazardous materials education and enforcement program that will focus on air freight forwarders. Also, shortly after August 1996, the FAA issued, under 14 CFR Part 109 (Indirect Air Carrier Security), shipper endorsement requirements that require all shippers, and freight forwarders to certify that all packages being shipped do not contain unauthorized explosives, destructive devices, or hazardous materials. Signing the endorsement also gives permission to search the shipment. Because the transport of oxygen generators has continued since the accident, despite the regulations, the Safety Board will closely monitor the FAA's progress in fulfilling these proposed improvements.

The FAA initiatives that have been undertaken since the ValuJet accident (e.g., hiring new agents, comprehensive inspections of carriers' and shippers' facilities, increased penalties for violations, a renewed outreach program, and the establishment of a database for trend analysis) are positive measures to reduce the number of hidden or undeclared shipments of hazardous materials. However, although the Safety Board supports these efforts, this accident illustrates that there is continued cause for concern. The Safety Board is especially concerned that, except in the case of properly packaged and declared shipments of hazardous materials, carriers generally do not inquire about the content of packages being shipped domestically, nor are they required to do so. The Safety Board also notes that the dangerous goods managers for FedEx and the FAA questioned the practicality and usefulness of carriers questioning a shipper about the contents of packages offered for shipment. Although air carriers and the FAA apparently agree on the seriousness of the problem, consideration is not being given to innovative measures, such as identifying package contents on the airbills or using technologies like x-ray machines to detect undeclared hazardous materials.

The Safety Board concludes that transportation of undeclared hazardous materials on airplanes remains a significant problem and more aggressive measures to address it are needed. Thus, the Safety Board believes that, in addition to the efforts already underway by the FAA, the DOT should require, within 2 years, that a person offering any shipment for air transportation provide written responses, on shipping papers, to inquiries about hazardous characteristics of the shipment, and develop other procedures and technologies to improve the detection of undeclared hazardous materials offered for transportation. The inquiries may include answering individual and specific questions about whether a package contains a substance that might be classified hazardous, (e.g., "does this package contain a substance that might be corrosive [or flammable, a poison, an oxidizer, etc.]")

As a result of the investigation of this accident, the National Transportation Safety Board recommends that the Department of Transportation:

> Require, within 2 years, that a person offering any shipment for air transportation provide written responses, on shipping papers, to inquiries about hazardous characteristics of the shipment, and develop other procedures and technologies to improve the detection of undeclared hazardous materials offered for transportation. (A-98-71)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 12, 1998

In reply refer to: A-98-72 through -79

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

About 0554 eastern daylight time,[1] on September 5, 1996, a Douglas DC-10-10CF, N68055, operated by the Federal Express Corporation (FedEx) as flight 1406, made an emergency landing at Stewart International Airport (Stewart), Newburgh, New York, after the flightcrew determined that there was smoke in the cabin cargo compartment. The flight was operating under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121 as a cargo flight from Memphis, Tennessee, to Boston, Massachusetts. Three crewmembers and two nonrevenue passengers were aboard the airplane. The captain and flight engineer sustained minor injuries while evacuating the airplane. The airplane was destroyed by fire after the landing.

The National Transportation Safety Board determined that the probable cause of this accident was an in-flight cargo fire of undetermined origin.[2]

Crew Coordination

Although the airplane was landed successfully, several required items were not accomplished during the descent and landing. The flight engineer failed to perform step No. 6 of the "Cabin Cargo Smoke Light Illuminated" checklist (pulling the cabin air shutoff T-handle).[3] If he had done so, airflow would have been shut off to the main cargo deck area while being maintained to the cockpit. The Safety Board concludes that the flight engineer's failure to pull the cabin air shutoff T-handle, as required by the "Cabin Cargo Smoke Light Illuminated" checklist, allowed the normal circulation of air to continue to enter the main cargo area, thereby providing the fire with a continuing source of oxygen and contributing to its rapid growth. However, the Safety Board could not determine the degree to which it might have contributed to the severity of the fire.

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[1] Unless otherwise indicated, all times are eastern daylight time, based on a 24-hour clock.

[2] National Transportation Safety Board. 1998. *In-Flight Fire/Emergency Landing, Federal Express Flight 1406, Douglas DC-10-10, N68055, Newburgh, New York, September 5, 1996.* Aircraft Accident Report NTSB/AAR-98/03. Washington, DC.

[3] Although the cockpit voice recorder (CVR) recorded the flight engineer stating, "pull cabin air" at 0538:40, its position after the accident indicates that the cabin air shutoff T-handle had not been pulled.

The flight engineer also failed to complete step No. 7 of the "Cabin Cargo Smoke Light Illuminated" checklist (to maintain a 0.5 psi differential cabin pressure). As a result, the occupants were unable to immediately open and exit from the primary evacuation exits (the L1 and R1 doors) because the airplane was still pressurized. The flight engineer acknowledged that instead of manually maintaining the appropriate pressure differential, after he had placed the outflow valve control in the manual position, he only "cranked it open a couple of times [turns]." Because they were at 33,000 feet and operating on only one pressurization pack, the outflow valve would have been almost completely closed before the flight engineer cranked it. As demonstrated in the Safety Board's test on a similar DC-10, manually cranking the outflow valve control two times will not perceptibly open the outflow valve from fully closed on a static airplane. The Safety Board concludes that the evacuation was delayed because the flightcrew failed to ensure that the airplane was properly depressurized.

The CVR transcript reveals that the flight engineer was overloaded and distracted from his attempts to accomplish the "Fire & Smoke" and "Cabin Cargo Smoke Light Illuminated" emergency checklists (in addition to his normal descent and before-landing checklist duties) by his repeatedly asking for the three-letter identifier for Stewart so that he could obtain runway data for that airport.

After the accident, the captain said that he had allowed the first officer to continue flying the airplane during the emergency so that he could coordinate with air traffic control and work with the flight engineer on completing the checklists. This should have resulted in an effective apportionment of the workload among the three crewmembers, in that the flying pilot would not have been overly distracted from flying the airplane, the flight engineer would have received needed assistance with his duties,[4] and the captain would have had the opportunity to oversee the actions of both. However, the Safety Board is concerned that, despite the captain's stated intention to serve in a monitoring and coordinating role, he failed to provide sufficient oversight and assistance to ensure completion of all necessary tasks.

The captain did not call for any checklists to address the smoke emergency, which was contrary to FedEx procedures.[5] (The flight engineer initiated the "Fire & Smoke" and "Cabin Cargo Smoke Light Illuminated" checklists.) Nor did he explicitly assign specific duties to each of the crewmembers. The captain also did not recognize the flight engineer's failure to accomplish required checklist items, provide the flight engineer with effective assistance, or intervene to adjust or prioritize his workload. In fact, the captain repeatedly interrupted the flight engineer during his attempts to complete the "Fire & Smoke" checklist,[6] thereby distracting him further from those duties.

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[4] At the time of the accident, the flight engineer had only 188 hours as a DC-10 flight engineer and had been working for FedEx for less than 6 months.

[5] The FedEx DC-10 Flight Manual indicates, under "Emergency and Abnormal Checklist Procedures," that "Phase One [memory]" items are to be "performed when directed by the Captain." Further, it states, "all checklists containing Phase One items should be requested by the Captain by name" and strongly recommends that the captain and flight engineer "work together on the review of the Phase One items and the accomplishment of the Phase Two items."

[6] At 0538:38 and 0539:13, the captain interrupted him to ask whether he had run a test on the smoke detector system, which is not an item listed on the checklist.

Further, the captain did not initiate the "Emergency Evacuation" checklist, which was required to be initiated during the preparation for landing. The "Emergency Evacuation" checklist includes depressurizing the airplane before landing. If this checklist had been initiated, it would have provided another opportunity for the crew to accomplish the necessary depressurization that was missed on the "Fire & Smoke" checklist. In addition, the captain told investigators that he did not initiate the emergency descent checklist, but said he thought he had accomplished the items on that checklist by memory. Although the emergency descent checklist (titled "Rapid Depressurization/Emergency Descent") was probably not applicable to this situation, the captain's statement is troubling because it suggests a belief that checklist items can be adequately accomplished from memory alone. Finally, the CVR transcript indicates that the captain did not call for an emergency evacuation. (After the captain said "we need to get...out of here," the flight engineer said "emergency ground egress.")

The Safety Board concludes that the captain did not adequately manage his crew resources when he failed to call for checklists or to monitor and facilitate the accomplishment of required checklist items. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require the principal operations inspector (POI) for FedEx to review the crew's actions on the accident flight and evaluate those actions in the context of FedEx emergency procedures and training (including procedures and training in crew resource management) to determine whether any changes are required in FedEx procedures and training.

Crew's Use of Emergency Equipment

Within 48 seconds after the first indication of a problem, the crew donned oxygen masks, as required by the "Fire & Smoke" checklist. The captain elected not to don his smoke goggles because they did not fit over his eyeglasses and they were dirty and scratched. The first officer elected not to wear his smoke goggles because he felt that they unduly restricted his peripheral vision. The flight engineer put his smoke goggles on but subsequently removed them because there was no smoke in the cockpit.

The Safety Board is concerned that cockpit smoke may affect crewmembers' vision, imperiling their ability to operate the airplane or properly address the emergency. Evidence in this accident indicates that smoke did not enter the cockpit in significant amounts until after the crew landed and stopped the airplane. However, the Safety Board is concerned that under different circumstances, the failure of crewmembers to don smoke goggles or to keep the goggles on during an emergency could adversely affect the outcome.

In connection with its investigation of the May 11, 1996, accident involving ValuJet flight 592,[7] the Safety Board concluded that there is inadequate guidance for air carrier pilots about the need to don oxygen masks and smoke goggles immediately in the event of a smoke emergency. In Safety Recommendation A-97-58, the Safety Board asked the FAA to issue guidance on this point to air carrier pilots. In a November 17, 1997, response, the FAA indicated it would issue a flight standards handbook bulletin in November 1997 containing guidance on procedures to don protective breathing equipment (PBE) for smoke and fume protection. The FAA did not issue the bulletin.

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[7] National Transportation Safety Board. 1997. *In-flight Fire and Impact with Terrain, ValuJet Airlines Flight 592, DC-9-32, N904VJ, Everglades, near Miami, Florida, May 11, 1996.* NTSB/AAR-97/06. Washington, DC.

Recently, it has been learned that the bulletin will not be issued until after the FAA reviews the results of a special emphasis inspection of smoke goggles during en route and ramp inspections. On March 20, 1998, the FAA called for this special survey of smoke goggles as part of its response to Safety Recommendation A-97-60 (also from the ValuJet report), which sought a requirement that smoke goggles currently approved for use by the flightcrews of transport-category aircraft be packaged in such a way that they can be easily opened by the flightcrew. The survey has been completed, and the FAA is reviewing the results. The Board has been assured that the FAA is still in agreement with the intent of the recommendations addressing flightcrew smoke goggles and that action on Safety Recommendations A-97-58, -59, and -60 will follow the results of the survey. The Board is very concerned that the issuance of the guidance bulletin regarding the need for flightcrews to don smoke goggles at the first indication of a possible in-flight smoke or fire emergency has been delayed until after the completion and review of the special survey. Based on this delay, the Board classifies Safety Recommendation A-97-58 "Open—Unacceptable Response."

In the ValuJet report, the Safety Board also concluded that the smoke goggle equipment currently provided on most air carrier transport aircraft requires excessive time, effort, attention, and coordination by the flightcrew to don and, in Safety Recommendation A-97-59, asked the FAA to establish a performance standard for the rapid donning of smoke goggles and ensure that all air carriers meet this standard through improved smoke goggle equipment, improved flightcrew training, or both. In response, the FAA indicated that it believed the intent of this recommendation is addressed in 14 CFR 121.337, which establishes standards for PBE for smoke and fume protection and requires that the equipment be conveniently located on the flight deck and easily accessible for immediate use. However, there is no standard for the optimum equipment location that will facilitate quick donning of such equipment or for the time required to don the equipment. The FAA also stated that it would issue a flight standards handbook bulletin to provide additional guidance on the location and donning of this equipment and procedural guidance on flightcrew training requirements. However, it did not address the recommendation to establish a standard to ensure that, through equipment design, equipment installation, or flightcrew training, a specific performance standard is achieved for donning smoke goggles. The FAA has indicated that it will await the results of the special emphasis inspection before it takes further action. The Safety Board classifies Safety Recommendation A-97-59 "Open—Unacceptable Response."

This accident again demonstrates that crews may not use the equipment currently available and that some characteristics of the current equipment may interfere with the flightcrew's performance of its duties. Accordingly, the Safety Board reiterates Safety Recommendations A-97-58 and -59.

During the evacuation, the flight engineer stated that before he entered the foyer area to evacuate via the R1 door, he filled his lungs with oxygen from his oxygen mask. He did not use the PBE, which would have provided him with protection from the smoke while he attempted to open the foyer doors. In postaccident interviews, he stated that he was anxious to open the exit doors quickly, and he forgot that the PBE was available. The Safety Board concludes that crewmembers who do not use PBE during a smoke or fire emergency may place themselves at unnecessary risk in attempting to address or escape from the situation. Although most carriers' emergency evacuation checklists instruct crewmembers to don PBE when circumstances warrant, there is no reference to the PBE in the FedEx "Emergency Evacuation" checklist. Therefore, the Safety Board believes that the FAA should require FedEx to modify its evacuation checklist and training to emphasize the availability of PBE during evacuations in an environment containing smoke, fire, or toxic fumes.

The L-1 door was not available as an emergency exit because it only opened partially as a result of the flight engineer's attempt to open the door while the airplane was still pressurized. When there is no electric power to the airplane the motor that operates the door is powered by a charged air bottle. If an attempt is made to open the door when the cabin pressure differential is above 0.5 psi, the bottle pressure will bleed off and the door will not open. Although the lack of the L-1 door as an escape route was not a significant factor in this accident, the Safety Board is concerned that under other circumstances the loss of a passenger exit door could have serious safety consequences. The Safety Board concludes that crewmembers may not be adequately aware that attempting to open a passenger exit door when the airplane is still pressurized may result in the door not opening. Therefore, the Safety Board believes that the FAA should require all Part 121 operators of airplanes that rely on air pressure to operate exit doors to make crewmembers aware of the circumstances of this accident and remind them of the need to ensure that the airplane is depressurized before attempting to open the passenger exit doors in an emergency.

Dissemination of Hazardous Materials Information

After the occupants had successfully evacuated the airplane, the most immediate problem for the firefighters and other emergency responders was to prevent the fire from spreading and involving the fuel that remained on the airplane. In this case, the unavailability to the incident commander of specific information about the declared hazardous materials on board did not affect the firefighting strategy of the New York Air National Guard (NY ANG). Nevertheless, in accidents that involve hazardous materials, it is critical that firefighters and other emergency responders receive timely information regarding the identity, quantity, number of packages, and location of declared hazardous materials. Such information can influence the type and level of response and may be necessary to adequately protect emergency response personnel, the environment, and the surrounding communities.

Neither the assistant fire chief who served as the initial incident commander nor the ANG fire chief received specific information during the firefighting phase of the emergency (before 0925) about the identity of the hazardous materials, their quantities, or the number of packages on the airplane. By 0700, about 1 hour after the airplane had landed, the only information about the hazardous materials on board the airplane that had been provided to the initial incident commander came from the Part A form and a handwritten list provided by the FedEx station at the airport. This information indicated only the hazard classes of the hazardous materials on board the airplane and their location in the airplane by cargo container position. Emergency guidance about specific chemicals was available through the Orange County Hazardous Materials Response Team (HMRT) and its communications link to CHEMTREC; however, this information was of little use until the specific identity and quantities of the declared hazardous materials on board the airplane were known. About 0915, approximately 10 minutes before the fire was extinguished, the fire chief received from the Orange County HMRT coordinator a copy of the weight and load plan and a handwritten list identifying some of the chemicals on board.

The NY ANG and other participating emergency response agencies, including airport operations at Stewart, repeatedly requested specific information about the hazardous materials on board the airplane. Throughout the morning (beginning at 0635) and into the early afternoon, FedEx, primarily through its Global Operations Command Center in Memphis, faxed as many as 12 transmissions of various hazardous materials shipping documents to the emergency operations center

(EOC) at the airport operations building and the New York State Police barracks at Stewart, although many of the faxes were illegible. However, none of these reached the incident commander.

Another problem was that FedEx did not have the capability to generate, in a timely manner, a single list indicating the shipping name, identification number, hazard class, quantity, number of packages, and the location of each declared shipment of hazardous materials on the airplane. To prepare such a list, FedEx would have had to compile information from copies of all of the individual Part Bs for each individual shipment of hazardous materials on the airplane. Because FedEx did not have the capability to quickly consolidate that information, it relied on faxing copies of the individual Part Bs for the approximately 85 hazardous materials packages on board, which proved to be burdensome, time consuming and, in this case, ineffective. Also, because of the poor quality and legibility of many of the handwritten Part Bs, much of the information was unusable.

In contrast, railroads operating freight trains can generate a computerized list of all of the freight cars in the train that identifies which freight cars are transporting hazardous materials and provides the shipping name, hazard class, identification number, and type of packaging, quantity, and emergency response guidance for each hazardous material transported. Such a printed, comprehensive list can be generated quickly and thus the information can be provided in a timely fashion to the appropriate emergency responders and in a more useful format than numerous faxed copies of partially legible Part B forms.

In both this accident and the July 31, 1997, crash of the FedEx MD-11 at Newark, the on-board Part B hazardous materials shipping papers were not available to emergency responders,[8] and FedEx was unable to provide complete information to emergency responders in a timely manner. Further, in two subsequent accidents (one near Clarksville, Tennessee, on March 5, 1998, and the other at Bismarck, North Dakota, on April 7, 1998), the effectiveness of FedEx's hazardous materials recordkeeping system was again called into question. In the Clarksville accident, the shipping papers on board the airplane and on file at FedEx's Memphis Operations Center were found to be inaccurate. And in the Bismarck accident, FedEx was unable to confirm whether there were hazardous materials on board the airplane until 2 hours and 49 minutes after receiving the request for this information.

Safety Board investigators surveyed the capability of other carriers to provide this information in similar circumstances and found that only one carrier had an on-line capability to provide detailed information about the hazardous materials on board its airplane. The remaining carriers, like FedEx, rely on paper copies of the hazardous material shipping documentation retained at the departing station if the on-board documentation is destroyed. The Safety Board is pleased that FedEx has committed to developing and implementing an electronic system for tracking and retrieving information about hazardous materials being carried on board FedEx flights. FedEx plans to implement intermediate and long-term plans that would make computerized information about hazardous materials information available from all FedEx facilities. However, the Safety Board does not agree with FedEx's position that the proper shipping name is not relevant to emergency responders. Although this information may not always be required, in many cases it may be vital

[8] The DOT hazardous materials regulations [49 CFR Part 173] require that the proper shipping name, hazard class, identification number, packaging group, and total quantity of the material appear on the shipping papers for any shipment of hazardous materials. Further, the regulations stipulate [49 CFR Part 175] that an operator must provide this information in writing to the pilot-in-command and that a copy of the shipping papers must accompany the shipment on board the airplane.

that emergency responders know exactly what substances are on board an aircraft so that appropriate measures can be taken to address potential risks.

Compared to the other modes of transportation, it is less likely that shipping papers on board an accident aircraft will survive or be accessible because of the greater likelihood of fire and destruction of the airplane. Because of the danger of fire, a flightcrew is also less likely to have time to retrieve the shipping papers after a crash. The Safety Board concludes that the DOT hazardous materials regulations do not adequately address the need for hazardous materials information on file at a carrier to be quickly retrievable in a format useful to emergency responders. Therefore, the Safety Board believes that the FAA and the Research and Special Programs Administration should require, within 2 years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated, specific information about the identity (including proper shipping name), hazard class, quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders.

Another obstacle in this case to emergency responders receiving hazardous materials information was FedEx's inappropriate statement to the ANG command post (at about 1300) that copies of the hazardous materials shipping documentation could not be provided to them because the Safety Board had taken over the investigation. This created the false impression that such information could not be released without the Safety Board's approval. FedEx later stated that this was consistent with company policy that once the Safety Board has taken control of an aircraft accident investigation, all information pertaining to that investigation should be forwarded to the Safety Board. Although the Safety Board appreciates FedEx's efforts to recognize the Board's primacy in aircraft accident investigations, the Safety Board has not promoted, nor does it support, a policy that would interfere with a carrier's ability to assist emergency responders in transportation emergencies, especially when hazardous materials are involved. The Safety Board concludes that FedEx's policy of providing information only to the Safety Board after the Safety Board initiates an investigation is inconsistent with the need to quickly provide emergency responders with essential information to assess the threat to themselves and the local community. Therefore, the Safety Board believes that the FAA should require the POI for FedEx to ensure that all FedEx employees who may communicate with emergency responders about a transportation accident involving hazardous materials understand that they should provide those emergency responders with any available information about hazardous materials that may be involved.

Emergency Response

Postaccident evaluations by airport personnel and representatives of the participating agencies indicated that many believed that communication and coordination among the agencies were lacking during the emergency response. Although all participating agencies recognized the ANG fire chief as the incident commander,[9] representatives from these agencies had differing opinions about who was to be present at the EOC, who was in charge at the EOC, the role of other agencies (including the Safety Board), and which emergency plan had been implemented in this accident. Although each of the participating agencies has conducted drills and exercises under their respective emergency plans for transportation and nontransportation hazardous materials incidents, joint exercises had not been conducted at Stewart for a simulated hazardous materials incident. The

[9] The assistant fire chief on duty served as incident commander until 0700, when the fire chief arrived on scene.

failure of the incident commander to receive the hazardous materials information that was being provided to other emergency responders indicates that communication and coordination among the participating agencies were not effective. Further, inadequate emergency preplanning and coordination among the responding emergency response agencies resulted in confusion about the responsibilities of the participating agencies and contributed to the failure of information about the hazardous materials on the airplane to reach the incident commander.

The Safety Board concludes that more effective preparation for emergencies involving hazardous materials and a system for coordination among the ANG, Stewart International Airport management, and all local and State emergency response agencies are needed. The Safety Board recognizes that after this accident Stewart revised its emergency plan, and that airport operations personnel at Stewart have acknowledged the need to address those deficiencies in the airport's emergency plan. However, the Safety Board is concerned that FAA requirements[10] do not specifically address the need to prepare for hazardous materials emergencies, and that other airports may be similarly unprepared for hazardous materials emergencies. The Safety Board concludes that airport emergency plans should specifically address hazardous materials emergencies. Therefore, the Safety Board believes that the FAA should require all certificated airports to coordinate with appropriate fire departments, and all State and local agencies that might become involved in responding to an aviation accident involving hazardous materials, to develop and implement a hazardous materials response plan for the airport that specifies the responsibility of each participating local, regional, and State agency, and addresses the dissemination of information about the hazardous materials involved. Such plans should take into consideration the types of hazardous materials incidents that could occur at the airport based on the potential types and sources of hazardous materials passing through the airport. The Safety Board also believes that the FAA should require airports to coordinate the scheduling of joint exercises to test these hazardous materials emergency plans.

Firefighters were positioned on scene before the airplane landed and began firefighting efforts immediately. Although the firefighters initially attempted to conduct an interior attack on the fire from the foyer area, the location of the cargo containers prevented them from approaching the seat of the fire. After the cargo door was opened, firefighters observed orange flames and heavy smoke in the airplane, and the incident commander evacuated them from the airplane. The initial incident commander's decision to evacuate the firefighters from the interior of the airplane was appropriate given the danger posed by the smoke and fire-filled airplane. However, the initial incident commander acknowledged that use of the skin penetrator agent application tool to penetrate the fuselage was delayed while he attempted to accommodate the flight engineer's request that damage to the airplane be minimized.[11] Although it is not clear whether an earlier entry would have improved the effectiveness of the firefighting efforts in this case, the Safety Board is concerned that more aggressive measures to enter the airplane, such as use of a fuselage penetrating tool, were not taken sooner. The Safety Board notes that the ANG fire chief testified that based on "lessons learned" from this accident, if a similar situation were to occur, he would immediately "get right in there with a hand line and deploy some type of penetrating tool on the outer skin of the aircraft."

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[10] 14 CFR 139.325 specifies what must be included in airport emergency plans of airports certificated under Part 139.

[11] The assistant fire chief who served as the initial incident commander testified that at the flight engineer's suggestion a telephone call was placed to the airplane manufacturer (Douglas) in an unsuccessful attempt to determine whether there were alternate means for entering the airplane.

The Safety Board has long been concerned about the lack of success of airport fire departments in extinguishing interior fires.[12] On June 4, 1996, the FAA published "Airport Rescue and Firefighting Mission Response Study," in the *Federal Register* and invited comments from interested parties. According to the *Federal Register* notice, the study was undertaken to compare the mission and requirements for civil airport fire services to those of the Department of Defense. On August 1, 1996, the Safety Board commented:

> [T]he current mission set forth in 14 CFR Part 139 to "provide an escape path from a burning airplane" no longer suffices. The Safety Board supports a full study of the mission statement by the FAA with a view towards providing adequate [aircraft rescue and firefighting (ARFF)] resources to rapidly extinguish aircraft interior fires and to extricate aircraft occupants from such interior fires. All aspects of this issue, including staffing, extinguishing agents, firefighter training, and response times, should be evaluated and compared with DOD standards to develop a broader mission statement that includes interior cabin fire suppression and extrication of aircraft occupants.

Accident history suggests that the environment inside a burning airplane's interior may be beyond the current technological capabilities of fire departments to extinguish within adequate time frames to successfully evacuate occupants or protect cargo. The Safety Board is aware that the FAA has researched fire extinguishing systems for airplane interiors, including testing of a water spray system that would discharge water into a particular area of the airplane when triggered by sensors in that area. Because the system would discharge water only to a focused area of potential fire, it would minimize the total amount of water that would need to be carried on board, thereby reducing the weight penalty of such a system. FAA tests showed that when this system was used to fight a fire, it delayed the onset of flashover, reduced cabin air temperatures, improved visibility, and increased potential survival time.

The Safety Board is concerned about the number of losses that have occurred and concludes that currently, inadequate means exist for extinguishing on-board aircraft fires. Therefore, the Safety Board believes that the FAA should reexamine the feasibility of on-board airplane cabin interior fire extinguishing systems for airplanes operating under 14 CFR Part 121 and, if found feasible, require the use of such systems.

The Safety Board realizes that requiring on-board extinguishing systems may not entirely resolve these safety concerns because they may become disabled by crash impacts. Further, the Safety Board realizes that the full implementation of such technology will require a number of years. Therefore, the Safety Board concludes that in addition to the safety benefits provided by on-board extinguishing systems, ARFF capabilities must also be improved so that firefighters are able to extinguish aircraft interior fires in a more timely and effective manner. Therefore, the Safety Board believes that the FAA should review the aircraft cabin interior firefighting policies, tactics, and

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[12] Air Canada DC-9-32 in Covington, Kentucky, June 2, 1983 (23 persons killed by smoke/and or fire); USAir 737 collision with a Skywest Fairchild Metro 227 in Los Angeles, California, on February 1, 1991 (22 persons killed by smoke/and or fire); Northwest Airlines DC-9 collision with a Northwest 727 in Detroit, Michigan, on December 3, 1990 (eight persons killed by smoke and/or fire); Air Transport International DC-8-62 in Jamaica, New York, on March 12, 1991 (freight only); Ryan International Airlines B-727 in Hartford, Connecticut, on May 3, 1991 (freight only); and TWA Lockheed L1011 in Jamaica, New York, on July 30, 1992.

procedures currently in use, and take action to develop and implement improvements in firefighter training and equipment to enable firefighters to extinguish aircraft interior fires more rapidly.

As a result of the investigation of this accident, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require the principal operations inspector for Federal Express (FedEx) to review the crew's actions on the accident flight and evaluate those actions in the context of FedEx emergency procedures and training (including procedures and training in crew resource management) to determine whether any changes are required in FedEx procedures and training. (A-98-72)
>
> Require Federal Express to modify its evacuation checklist and training to emphasize the availability of protective breathing equipment during evacuations in an environment containing smoke, fire, or toxic fumes. (A-98-73)
>
> Require all Part 121 operators of airplanes that rely on air pressure to open exit doors to make crewmembers aware of the circumstances of this accident and remind them of the need to ensure that the airplane is depressurized before attempting to open the passenger exit doors in an emergency. (A-98-74)
>
> Require, within 2 years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated, specific information about the identity (including proper shipping name), hazard class, quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders. (A-98-75)
>
> Require the principal operations inspector for Federal Express (FedEx) to ensure that all FedEx employees who may communicate with emergency responders about a transportation accident involving hazardous materials understand that they should provide those emergency responders with any available information about hazardous materials that may be involved. (A-98-76)
>
> Require all certificated airports to coordinate with appropriate fire departments, and all State and local agencies that might become involved in responding to an aviation accident involving hazardous materials, to develop and implement a hazardous materials response plan for the airport that specifies the responsibility of each participating local, regional, and State agency, and addresses the dissemination of information about the hazardous materials involved. Such plans should take into consideration the types of hazardous materials incidents that could occur at the airport based on the potential types and sources of hazardous materials passing through the airport. Airports should also be required to coordinate the scheduling of joint exercises to test these hazardous materials emergency plans. (A-98-77)
>
> Reexamine the feasibility of on-board airplane cabin interior fire extinguishing systems for airplanes operating under 14 Code of Federal Regulations Part 121 and, if found feasible, require the use of such systems. (A-98-78)

Review the aircraft cabin interior firefighting policies, tactics, and procedures currently in use, and take action to develop and implement improvements in firefighter training and equipment to enable firefighters to extinguish aircraft interior fires more rapidly. (A-98-79)

Additionally, the Safety Board reiterates the following recommendations to the FAA:

Issue guidance to air carrier pilots about the need to don oxygen mask and smoke goggles at the first indication of a possible in-flight smoke or fire emergency. (A-97-58)

Establish a performance standard for the rapid donning of smoke goggles; then ensure that all air carriers meet this standard through improved smoke goggle equipment, improved training, or both. (A-97-59)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 12, 1998

In reply refer to: A-98 -80

Ms. Kelley S. Coyner
Office of the Administrator
Research and Special Programs Administration
400 7th Street, S.W.
Washington, D.C. 20590

About 0554 eastern daylight time,[1] on September 5, 1996, a Douglas DC-10-10CF, N68055, operated by the Federal Express Corporation (FedEx) as flight 1406, made an emergency landing at Stewart International Airport (Stewart), Newburgh, New York, after the flightcrew determined that there was smoke in the cabin cargo compartment. The flight was operating under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121 as a cargo flight from Memphis, Tennessee, to Boston, Massachusetts. Three crewmembers and two nonrevenue passengers were aboard the airplane. The captain and flight engineer sustained minor injuries while evacuating the airplane. The airplane was destroyed by fire after the landing.

The National Transportation Safety Board determined that the probable cause of this accident was an in-flight cargo fire of undetermined origin.[2]

After the occupants had successfully evacuated the airplane, the most immediate problem for the firefighters and other emergency responders was to prevent the fire from spreading and involving the fuel that remained on the airplane. In this case, the unavailability to the incident commander of specific information about the declared hazardous materials on board did not affect the firefighting strategy of the New York Air National Guard (NY ANG). Nevertheless, in accidents that involve hazardous materials, it is critical that firefighters and other emergency responders receive timely information regarding the identity, quantity, number of packages, and location of declared hazardous materials. Such information can influence the type and level of response and may be necessary to adequately protect emergency response personnel, the environment, and the surrounding communities.

Neither the assistant fire chief who served as the initial incident commander nor the ANG fire chief received specific information during the firefighting phase of the emergency (before

[1] Unless otherwise indicated, all times are eastern daylight time, based on a 24-hour clock.

[2] National Transportation Safety Board. 1998. *In-Flight Fire/Emergency Landing, Federal Express Flight 1406, Douglas DC-10-10, N68055, Newburgh, New York, September 5, 1996.* Aircraft Accident Report NTSB/AAR-98/03. Washington, DC.

0925) about the identity of the hazardous materials, their quantities, or the number of packages on the airplane. By 0700, about 1 hour after the airplane had landed, the only information about the hazardous materials on board the airplane that had been provided to the initial incident commander came from the Part A form and a handwritten list provided by the FedEx station at the airport. This information indicated only the hazard classes of the hazardous materials on board the airplane and their location in the airplane by cargo container position. Emergency guidance about specific chemicals was available through the Orange County Hazardous Materials Response Team (HMRT) and its communications link to CHEMTREC; however, this information was of little use until the specific identity and quantities of the declared hazardous materials on board the airplane were known. About 0915, approximately 10 minutes before the fire was extinguished, the fire chief received from the Orange County HMRT coordinator a copy of the weight and load plan and a handwritten list identifying some of the chemicals on board.

The NY ANG and other participating emergency response agencies, including airport operations at Stewart, repeatedly requested specific information about the hazardous materials on board the airplane. Throughout the morning (beginning at 0635) and into the early afternoon, FedEx, primarily through its Global Operations Command Center in Memphis, faxed as many as 12 transmissions of various hazardous materials shipping documents to the emergency operations center at the airport operations building and the New York State Police barracks at Stewart, although many of the faxes were illegible. However, none of these reached the incident commander.

Another problem was that FedEx did not have the capability to generate, in a timely manner, a single list indicating the shipping name, identification number, hazard class, quantity, number of packages, and the location of each declared shipment of hazardous materials on the airplane. To prepare such a list, FedEx would have had to compile information from copies of all of the individual Part Bs for each individual shipment of hazardous materials on the airplane. Because FedEx did not have the capability to quickly consolidate that information, it relied on faxing copies of the individual Part Bs for the approximately 85 hazardous materials packages on board, which proved to be burdensome, time consuming and, in this case, ineffective. Also, because of the poor quality and legibility of many of the handwritten Part Bs, much of the information was unusable.

In contrast, railroads operating freight trains can generate a computerized list of all of the freight cars in the train that identifies which freight cars are transporting hazardous materials and provides the shipping name, hazard class, identification number, and type of packaging, quantity, and emergency response guidance for each hazardous material transported. Such a printed, comprehensive list can be generated quickly and thus the information can be provided in a timely fashion to the appropriate emergency responders and in a more useful format than numerous faxed copies of partially legible Part B forms.

In both this accident and the July 31, 1997, crash of the FedEx MD-11 at Newark, the on-board Part B hazardous materials shipping papers were not available to emergency responders,[3]

[3] The Department of Transportation (DOT) hazardous materials regulations [49 CFR Part 173] require that the proper shipping name, hazard class, identification number, packaging group, and total quantity of the material

and FedEx was unable to provide complete information to emergency responders in a timely manner. Further, in two subsequent accidents (one near Clarksville, Tennessee, on March 5, 1998, and the other at Bismarck, North Dakota, on April 7, 1998), the effectiveness of FedEx's hazardous materials recordkeeping system was again called into question. In the Clarksville accident, the shipping papers on board the airplane and on file at FedEx's Memphis Operations Center were found to be inaccurate. And in the Bismarck accident, FedEx was unable to confirm whether there were hazardous materials on board the airplane until 2 hours and 49 minutes after receiving the request for this information.

Safety Board investigators surveyed the capability of other carriers to provide this information in similar circumstances and found that only one carrier had an on-line capability to provide detailed information about the hazardous materials on board its airplane. The remaining carriers, like FedEx, rely on paper copies of the hazardous material shipping documentation retained at the departing station if the on-board documentation is destroyed. The Safety Board is pleased that FedEx has committed to developing and implementing an electronic system for tracking and retrieving information about hazardous materials being carried on board FedEx flights. FedEx plans to implement intermediate and long-term plans that would make computerized information about hazardous materials information available from all FedEx facilities. However, the Safety Board does not agree with FedEx's position that the proper shipping name is not relevant to emergency responders. Although this information may not always be required, in many cases it may be vital that emergency responders know exactly what substances are on board an aircraft so that appropriate measures can be taken to address potential risks.

Compared to the other modes of transportation, it is less likely that shipping papers on board an accident aircraft will survive or be accessible because of the greater likelihood of fire and destruction of the airplane. Because of the danger of fire, a flightcrew is also less likely to have time to retrieve the shipping papers after a crash. The Safety Board concludes that the DOT hazardous materials regulations do not adequately address the need for hazardous materials information on file at a carrier to be quickly retrievable in a format useful to emergency responders. Therefore, the Safety Board believes that the Federal Aviation Administration and the Research and Special Programs Administration should require, within 2 years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated, specific information about the identity (including proper shipping name), hazard class, quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders.

As a result of the investigation of this accident, the National Transportation Safety Board recommends that the Research and Special Programs Administration:

> Require, within 2 years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated specific information about the identity (including proper shipping name), hazard class,

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appear on the shipping papers for any shipment of hazardous materials. Further, the regulations stipulate [49 CFR Part 175] that an operator must provide this information in writing to the pilot-in-command and that a copy of the shipping papers must accompany the shipment on board the airplane.

quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders. (A-98-80)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: August 20, 1998

In reply refer to: A-98-83

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On February 20, 1997, Mesaba Airlines flight 3098, a de Havilland DHC-8-102, N828MA, operated as a Title 14 Code of Federal Regulations Part 121 flight, experienced an uncommanded left roll after departure from Detroit Wayne County Metropolitan Airport (DTW), Michigan. The flightcrew maintained control of the airplane with opposite aileron and aileron trim input. The captain reported that excessive right-wing-down trim was necessary to maintain a wings-level attitude and that the powered flight control surfaces (PFCS) display in the cockpit indicated that the left, outboard spoiler was deployed approximately 50 percent. The flightcrew depressurized the affected roll spoiler hydraulic circuit, but the spoiler remained in the partially extended position. The flightcrew declared an emergency, but the airplane landed at DTW without further incident. There were no injuries to the 3 crewmembers or 23 passengers on the airplane. Visual meteorological conditions prevailed at the time of the incident.

Postflight examination of the airplane confirmed that the left, outboard roll spoiler[1] remained partially deployed. The spoiler actuator was disassembled and examined by Dowty Aerospace (Dowty), the manufacturer of the actuator, and the National Transportation Safety Board. The examination revealed that the welded plug at the base of the actuator piston had separated and lodged between the piston and the housing. This restricted the piston's travel and prevented its full retraction.

The Safety Board has investigated two other incidents in which DHC-8 roll spoiler actuators became jammed in an extended position during flight. On January 22, 1997, a

[1] Each wing contains inboard and outboard roll spoilers that deploy proportionally with upward travel of the aileron.

Mesaba Airlines DHC-8, N852MA, experienced an uncommanded left roll during takeoff rotation at Charleston, West Virginia. The captain reported that he applied full left control wheel input to counter heavy left crosswinds experienced on the runway. The captain stated that the airplane rolled left during rotation and that substantial right aileron and rudder inputs were necessary to arrest the roll rate. The crew maintained aileron and rudder inputs to stabilize the roll and continued climbing while they performed the emergency checklist procedure for "airplane rolls with no control wheel input." The flightcrew declared an emergency, but the landing was executed without further incident. The PFCS display and postflight inspection indicated that the left, inboard roll spoiler was extended approximately 50 percent. Examination of the spoiler actuator revealed failure of the welded plug at the base of the actuator piston that prevented full retraction of the piston.

The other incident involved a Mesaba Airlines DHC-8, N828MA, that experienced an uncommanded left roll during the approach to land at Moline, Illinois, on April 3, 1995. The flightcrew reported that right aileron was required to maintain wings-level flight. The flightcrew declared an emergency, but the airplane landed without further incident. The PFCS display and postflight inspection indicated that the left, inboard roll spoiler was extended approximately 50 percent. Examination of the spoiler actuators revealed a similar failure of the welded plug at the base of the actuator piston.

In addition to the three incidents investigated by the Safety Board, Dowty reported that it is aware of seven additional actuators that experienced similar failure of the welded plug and jamming of the piston. All of the failures have been attributed to improper welds of the plug at the base of the piston. Failure of the piston plug allows hydraulic fluid to fill the interior chamber of the piston yet continue to actuate the piston. Failure of the piston plug does not affect hydraulic system integrity or operation of the actuator piston in the extended direction; however, it does prevent the actuator piston from fully retracting from an extended position.

Dowty decided to discontinue manufacturing the welded-plug piston assemblies (part number (P/N) A50991-2) for the DHC-8 roll spoiler actuator and to purge its stock after the April 3, 1995, incident involving N828MA. A new piston assembly (P/N A44714-2) was introduced that incorporates a swaged piston blank in lieu of the welded-plug design. There have been no reported failures of the new piston assembly, which has been incorporated on all DHC-8 roll spoiler actuators manufactured or repaired by Dowty since April 1995. However, Dowty and de Havilland stated that most of the 516 actuators that were manufactured with the welded-plug design (only for DHC-8 airplanes) remain in service.

On July 15, 1997, de Havilland issued an In-Service Activities Report (ISAR) to inform DHC-8 operators about this roll spoiler problem. The ISAR also referenced a pending Dowty service letter (subsequently issued on September 26, 1997), which provided details about modifying in-service actuators with the new piston assembly. The ISAR further stated that the problem involving the roll spoiler actuators "is not considered to be a safety issue" because it only affects operation of the roll spoiler through part of its stroke and is readily detectable. However, the Safety Board is concerned that the lateral asymmetry resulting from a jammed roll spoiler could be hazardous during certain operations that are frequently encountered, such as flight at low airspeeds or during heavy crosswinds or turbulence. Accordingly, the Safety Board believes that the Federal Aviation Administration should require that operators of de Havilland DHC-8 airplanes replace the welded-plug piston assembly (P/N A50991-2) on Dowty roll spoiler actuators with a piston assembly using a swaged piston blank.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require that operators of de Havilland DHC-8 airplanes replace the welded-plug piston assembly (part number A50991-2) on Dowty Aerospace roll spoiler actuators with a piston assembly using a swaged piston blank. (A-98-83)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: September 8, 1998
In reply refer to: A-98-84 through -86

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On January 12, 1997, about 1026 Hawaiian standard time, a McDonnell Douglas Helicopter Systems (MDHS)[1] 369D helicopter, N7012G, powered by one Allison 250-C20B turboshaft engine, lost engine power about 150 feet above ground level (agl) shortly after takeoff from a helipad near Kamuela, Hawaii. The pilot initiated an autorotation, but the helicopter landed hard in an open field, resulting in the main rotor blades severing the tailboom. The helicopter was substantially damaged; however, the pilot was not injured. No flight plan was filed, and visual meteorological conditions prevailed at the time of the accident. The flight was operated under Title 14 Code of Federal Regulations Part 91 as a personal flight.

The MDHS 369 series (formerly Hughes 369 series) has one two-cell fuel tank. The airframe fuel system has a fuel tank boost pump to provide positive-pressure fuel delivery to the engine for starting. The engine-driven fuel pump provides high-pressure fuel to the fuel control unit (FCU), which meters fuel to the fuel nozzle. The fuel nozzle is a two-stage single-barrel fuel delivery device providing fuel to the engine for starting and fuel spray for continuous operation. The Allison 250 series engine has three fuel straining devices to prevent contaminants in the fuel from reaching the engine. The fuel pump has a two-stage filter with a bypass and pressure sensor to activate a warning light in the cockpit if the fuel flow through the filter is obstructed (impending bypass). The FCU has an inlet fuel screen with a bypass feature with no associated warning indication. The fuel nozzle has a fuel screen with neither a bypass feature nor an associated warning indicator.

During the investigation of the Kamuela, Hawaii, accident, Safety Board investigators found that the fuel nozzle screen was contaminated with foreign material, including sodium chloride (salt). Contamination was also found in the fuel pump filter and FCU screen of the engine fuel system.

[1] The MDHS commercial helicopter division was recently acquired by Boeing Aircraft Company.

The maintenance records indicated that the helicopter had been inspected in accordance with the manufacturer's recommended 100/300-hour inspection procedures about 21 flight hours before the accident. The inspection procedures did not include inspecting the fuel nozzle screen nor the FCU screen, but did include replacement of the engine fuel pump filter. The engine manufacturer's inspection guidelines recommend that the fuel nozzle screen be inspected only when the engine fuel filter bypass light illuminates and/or the engine fuel pump filter is found to be contaminated. The maintenance records did not indicate a contaminated fuel filter during the 100/300-hour inspection nor had there been any reports of an illuminated fuel filter bypass light. The fuel nozzle has an overhaul time limit of 2,500 flight hours with no requirement for regularly scheduled interim inspections. The accident nozzle had accumulated about 317 flight hours since overhaul. The engine had been operated in a salt water environment, and its maintenance records showed that it had been subject to regular wash procedures (see enclosed Brief of Accident File No. 654).

The Safety Board is aware of three similar accidents involving fuel nozzle screen contamination of Allison 250 series engines. On November 16, 1996, near Forks, Washington, a Hughes 369D helicopter, registration N5225C, lost engine power during an external load operation. The helicopter received substantial damage when it collided with trees during its autorotational descent. The investigation revealed contamination throughout the helicopter's fuel system. The fuel filters were contaminated and in the bypass mode, and the fuel nozzle screen was found partially blocked by contaminants. The fuel contaminants were traced to the operator's in-ground storage tanks (see enclosed Brief of Accident File No. 1569).

On April 14, 1996, near Yerington, Nevada, a Hughes 369D helicopter, registration N519BH, lost engine power during cruise flight at 200 to 300 feet agl. The subsequent engine-out emergency landing resulted in substantial damage to the helicopter. The helicopter had an annual inspection 6 months before the accident. The last compressor wash was 2 months before the flight, and the helicopter had been flown 8 hours since the compressor wash. Examination of the FCU inlet screen and the fuel pump fuel filter did not reveal contaminants; however, the engine flamed out during the initial postaccident engine test run and experienced consistent engine power degradation in all tests. Inspection of the engine fuel nozzle after the test runs revealed a partially blocked screen (see enclosed Brief of Accident No. 689).

On April 18, 1994, a Hughes 369D helicopter, registration N1103N, lost engine power during a sightseeing flight near Hanapepe, Hawaii. While maneuvering, the engine suddenly lost power, and, after an autorotation, the helicopter landed hard on rocky terrain. Examination of the engine fuel system revealed that the fuel nozzle screen was obstructed by contaminants, including salt. The helicopter was operated in a marine environment with substantial operations over the ocean. The maintenance procedures used by the company included daily engine compressor rinses (see enclosed Brief of Accident No. 1416).

In addition to the above-mentioned accidents, investigators found a Federal Aviation Administration (FAA) maintenance periodical, Advisory Circular No. 43.16, titled "General

Aviation Airworthiness Alerts," which described an incident that involved an Allison 250-C20 engine installed in a Hughes 369D helicopter. During flight, the engine reportedly lost power without warning; however, the pilot performed a successful autorotational landing. The investigation revealed a severely restricted fuel nozzle screen. The fuel nozzle's historical flight hours and the contaminants blocking the screen were not reported.

The Safety Board's staff also found that numerous malfunction or defect reports of partially clogged Allison 250 engine fuel nozzles have been submitted by mechanics. These fuel nozzles are not removed based on a schedule provided by the manufacturer, but based on deteriorating engine performance or the mechanic's personal experience. Because these measures have not proved adequate, corrective action is needed to address the engine power losses that have been caused by contamination of Allison 250 series fuel nozzle screens. The Safety Board believes that the FAA should direct all operators of helicopters powered by Allison 250 series engines to conduct a one-time inspection of all the engine fuel nozzle screens to ensure that they are intact, unobstructed, and functional. After the one-time inspection, the Safety Board believes that the FAA should determine appropriate inspection intervals for helicopters powered by Allison 250 series turboshaft engines and then require that periodic inspections be accomplished on those engine fuel nozzle screens to prevent the accumulation of contaminants that could alter the fuel delivery, engine performance, and ultimately clog the fuel nozzle screen and cause engine power loss.

The Safety Board notes that of those occurrences known to the Board, all of the MDHS 369 helicopters involved in fuel nozzle screen anomalies have not had an airframe-mounted fuel filter installed, which is optional on MDHS 369 series and some other makes of helicopters. Although the airframe-mounted fuel filter does not capture smaller particles than the fuel pump filter, the airframe-mounted filter does afford greater surface area filtration. Also, the fuel nozzles installed on Allison 250 series engines do not have a fail-safe design (bypass feature), even though a failure or obstruction of the nozzle results in complete loss of engine power. Therefore, the Safety Board believes that the FAA should determine if the optional airframe-mounted fuel filter on helicopters powered by Allison 250 series engines provides substantial improvement in the removal of fuel system contaminants, and, if so, require airframe-mounted fuel filters on those helicopters that do not already have them installed.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Direct all operators of helicopters powered by Allison 250 series engines to conduct a one-time inspection of all the engine fuel nozzle screens to ensure that they are intact, unobstructed, and functional. (A-98-84)
>
> Determine appropriate inspection intervals for helicopters powered by Allison 250 series turboshaft engines and then require that periodic inspections be accomplished on those engine fuel nozzle screens to prevent the accumulation of contaminants that could alter the fuel

delivery, engine performance, and ultimately clog the fuel nozzle screen and cause engine power loss. (A-98-85)

Determine if the optional airframe-mounted fuel filter on helicopters powered by Allison 250 series engines provides substantial improvement in the removal of fuel system contaminants, and, if so, require airframe-mounted fuel filters on those helicopters that do not already have them installed. (A-98-86)

Chairman HALL, Vice Chairman FRANCIS, and Member HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

Enclosures

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 02/02/1998

LAX97LA088
FILE NO. 654 01/12/97 KAMUELA,HI AIRCRAFT REG. NO. N7012G TIME (LOCAL) - 10:26 HST

MAKE/MODEL - McDonnell Douglas 369D
ENGINE MAKE/MODEL - Allison 250-C20B
AIRCRAFT DAMAGE - Substantial
NUMBER OF ENGINES - 1

	FATAL	SERIOUS	MINOR/NONE
CREW	0	0	1
PASS	0	0	0

OPERATING CERTIFICATES - On-demand air taxi
- Rotorcraft-external load operator
TYPE OF FLIGHT OPERATION - Positioning
REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 91

LAST DEPARTURE POINT - Same as Accident
DESTINATION - Local

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 0010.000 SM
WIND DIR/SPEED - 340 /008 KTS
TEMPERATURE (F) - 77
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 37

CERTIFICATES/RATINGS
Commercial
Helicopter
INSTRUMENT RATINGS
Helicopter

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 9400
LAST 90 DAYS - Unk/Nr
TOTAL MAKE/MODEL - Unk/Nr
TOTAL INSTRUMENT TIME - Unk/Nr

The helicopter was being operated in a marine environment. The pilot reported he lost engine power during the initial takeoff climb and autorotated to an open field. The helicopter landed hard and the main rotor blades severed the tailboom. Examination of the engine fuel filter, the fuel control unit (FCU) screen, and the fuel nozzle screen revealed contamination in the fuel system. The helicopter had been inspected in accordance with the manufacturer's 100/300 hour inspection about 21.2 flight hours before the accident. There were no reports of the engine fuel filter bypassing or the fuel filter caution light illuminating. The manufacturer's inspection program does not require the inspection of the fuel screens at the 100 or 300 hour intervals. The airframe manufacturer's maintenance manual does indicate that a conditional inspection be performed after the fuel filter caution light has illuminated. Review of the conditional inspection procedures revealed the FCU screen is to be removed and cleaned; however, there is no requirement for the removal and cleaning of the nozzle screen, which is downstream of the FCU screen, before the part's 2,500 hour overhaul cycle.

LAX97LA088
FILE NO. 654 | 01/12/97 | KAMUELA,HI | AIRCRAFT REG. NO. N7012G | TIME (LOCAL) - 10:26 HST

Occurrence# 1 LOSS OF ENGINE POWER(PARTIAL) - MECH FAILURE/MALF
Phase of Operation TAKEOFF - INITIAL CLIMB

Findings
1. - FUEL SYSTEM - CONTAMINATION
2. - FUEL SYSTEM,NOZZLE - BLOCKED(PARTIAL)
3. - PROCEDURE INADEQUATE - MANUFACTURER
4. - INSUFFICIENT STANDARDS/RQRMNTS,MANUFACTURER - MANUFACTURER
5. - FLUID,FUEL - OBSTRUCTED
6. - TURBOSHAFT ENGINE - OUTPUT LOW

Occurrence# 2 FORCED LANDING
Phase of Operation EMERGENCY LANDING AFTER TAKEOFF

Occurrence# 3 HARD LANDING
Phase of Operation LANDING - FLARE/TOUCHDOWN

Findings
7. - TERRAIN CONDITION - GROUND
8. - AUTOROTATION - IMPROPER - PILOT-IN-COMMAND
9. - ROTOR RPM - NOT MAINTAINED - PILOT-IN-COMMAND

The National Transportation Safety Board determines that the probable cause(s) of this accident was:
fuel system contamination resulting in a partial loss of power, and the failure of the pilot to maintain adequate rotor rpm to cushion the autorotative landing and prevent main rotor blade contact with the tailboom. Factors were the inadequacy of manufacturer's maintenance inspection procedures for aircraft operated in a marine environment.

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 08/21/1997

SEA97LA032
FILE NO. 1569 11/16/96 FORKS,WA AIRCRAFT REG. NO. N5225C TIME (LOCAL) - 15:00 PST

MAKE/MODEL - Hughes 369D
ENGINE MAKE/MODEL - Allison 250-C20B
AIRCRAFT DAMAGE - Substantial
NUMBER OF ENGINES - 1

	FATAL	SERIOUS	MINOR/NONE
CREW	0	1	0
PASS	0	0	0

OPERATING CERTIFICATES - Rotorcraft-external load operator
TYPE OF FLIGHT OPERATION - Other work use
REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 133

LAST DEPARTURE POINT - Same as Accident
DESTINATION - Local

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight

WEATHER INFO SOURCE- Pilot

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - 2000 FT Broken
VISIBILITY - 0003.000 SM
WIND DIR/SPEED - 225 /005 KTS
TEMPERATURE (F) - 40
OBSTR TO VISION - None
PRECIPITATION - Unk/Nr

PILOT-IN-COMMAND AGE - 50

CERTIFICATES/RATINGS
Commercial
Helicopter
INSTRUMENT RATINGS
Helicopter

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 18610
LAST 90 DAYS - Unk/Nr
TOTAL MAKE/MODEL - 5825
TOTAL INSTRUMENT TIME - Unk/Nr

The helicopter lost engine power during an external load/logging operation, then it sustained substantial damage when it collided with trees during an emergency landing. Investigation revealed that fuel contamination disrupted the flow of fuel from the engine fuel nozzle(s). Test samples from the fuel supplier, storage tank, and the helicopter's fuel filter were provided by the operator to an independent laboratory. Testing showed that the fuel supplier's sample was free of contamination, but contamination was found in samples from the storage tank and the helicopter fuel filter.

SEA97LA032
FILE NO. 1569   11/16/96   FORKS,WA   AIRCRAFT REG. NO. N5225C   TIME (LOCAL) - 15:00 PST

Occurrence# 1   LOSS OF ENGINE POWER(TOTAL) - NON-MECHANICAL
Phase of Operation   MANEUVERING

Findings
1. - FLUID,FUEL - CONTAMINATION,OTHER THAN WATER
2. - MAINTENANCE,SERVICE OF AIRCRAFT - IMPROPER

Occurrence# 2   FORCED LANDING
Phase of Operation   EMERGENCY DESCENT/LANDING

Findings
3. - AUTOROTATION - PERFORMED - PILOT-IN-COMMAND

Occurrence# 3   IN-FLIGHT COLLISION WITH OBJECT
Phase of Operation   EMERGENCY LANDING

Findings
4. - TERRAIN CONDITION - NONE SUITABLE
5. - OBJECT - TREE(S)

The National Transportation Safety Board determines that the probable cause(s) of this accident was: fuel contamination, which resulted in loss of engine power. **Factors relating to the accident included:** improper servicing of the helicopter, and a lack of suitable terrain for an emergency landing due to the proximity of trees.

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 12/16/1996

LAX96LA168
FILE NO. 689 04/14/96 YERINGTON,NV AIRCRAFT REG. NO. N519BH TIME (LOCAL) - 11:55 PDT

MAKE/MODEL - Hughes 369D
ENGINE MAKE/MODEL - Allison 250-C20B
AIRCRAFT DAMAGE - Substantial
NUMBER OF ENGINES - 1

	FATAL	SERIOUS	MINOR/NONE
CREW	0	0	1
PASS	0	0	2

OPERATING CERTIFICATES - None
TYPE OF FLIGHT OPERATION - Personal
REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 91

LAST DEPARTURE POINT - Same as Accident
DESTINATION - Local

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight

WEATHER INFO SOURCE- Pilot

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 0050.000 SM
WIND DIR/SPEED - 315 /005 KTS
TEMPERATURE (F) - 70
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 68

CERTIFICATES/RATINGS
Private
Single-engine land, Multiengine land
Helicopter, Free balloon, Glider
INSTRUMENT RATINGS
None

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 6348
LAST 90 DAYS - 8
TOTAL MAKE/MODEL - 176
TOTAL INSTRUMENT TIME - Unk/Nr

The pilot experienced a total loss of engine power while cruising between 200 and 300 feet above ground level and at an airspeed of 100 knots. The pilot reported that the engine noise resembled the same whining as if it were in a shut down mode. The pilot entered an autorotation and landed in an open field approximately 0.5 miles from his airstrip. The accident site examination revealed that the helicopter had touched down with forward speed and made depressions in the soft ground over a distance of 25 to 30 feet. The helicopter rolled onto its side and a main rotor blade severed the tail boom. Tail rotor blade and drive shaft components separated from the helicopter and were found 200 feet from the main wreckage. The last annual inspection was performed 6 months prior to the accident flight and the aircraft had flown 16.9 hours. Also, the last compressor wash was performed about 2 months prior to the flight and had flown 8 hours since then. The postaccident engine examination revealed accumulated nozzle port debris and dirty compressor blades and vanes. The engine flamed out during its first test run and, during subsequent tests, it produced power 7.8 percent below specifications.

LAX96LA168
FILE NO. 689 | 04/14/96 | YERINGTON,NV | AIRCRAFT REG. NO. N519BH | TIME (LOCAL) - 11:55 PDT

Occurrence# 1 LOSS OF ENGINE POWER(PARTIAL) - NON-MECHANICAL
Phase of Operation CRUISE - NORMAL

Findings
1. - FUEL SYSTEM,NOZZLE - CONTAMINATION
2. - COMPRESSOR ASSEMBLY,BLADE - DIRTY(FOGGY)

Occurrence# 2 FORCED LANDING
Phase of Operation EMERGENCY DESCENT/LANDING

Findings
3. - AUTOROTATION - PERFORMED - PILOT-IN-COMMAND

Occurrence# 3 ROLL OVER
Phase of Operation LANDING - FLARE/TOUCHDOWN

Findings
4. - FLARE - MISJUDGED - PILOT-IN-COMMAND
5. - TERRAIN CONDITION - OPEN FIELD
6. - TERRAIN CONDITION - SOFT

The National Transportation Safety Board determines that the probable cause(s) of this accident was: the partial loss of engine power and the pilot's misjudged flare during an autorotation landing in soft dirt with excessive forward speed. The power loss resulted from flight operations in an environment which debris contaminated the engine's nozzle port and compressor assembly.

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 04/07/1995

LAX94FA197
FILE NO. 1416 04/18/94 HANAPEPE,HI AIRCRAFT REG. NO. N1103N TIME (LOCAL) - 13:14 HST

MAKE/MODEL - HUGHES 369D
ENGINE MAKE/MODEL - ALLISON 250-C20B
AIRCRAFT DAMAGE - Destroyed
NUMBER OF ENGINES - 1

	FATAL	SERIOUS	MINOR/NONE
CREW	0	1	0
PASS	1	3	0

OPERATING CERTIFICATES - On-demand air taxi
- Rotorcraft-external load operator

TYPE OF FLIGHT OPERATION - SIGHTSEEING
REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 91

LAST DEPARTURE POINT - Same as Accident
DESTINATION - Local

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 0015.000 SM
WIND DIR/SPEED - 040 /018 KTS
TEMPERATURE (F) - 77
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 32

CERTIFICATES/RATINGS
Commercial
Helicopter
INSTRUMENT RATINGS
None

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 3100
LAST 90 DAYS - 40
TOTAL MAKE/MODEL - 2200
TOTAL INSTRUMENT TIME - 110

THE PILOT REPORTED THAT WHILE MANEUVERING NEAR A WATERFALL ON A SIGHT-SEEING FLIGHT, THE HUGHES 369D SUSTAINED A LOSS OF ENGINE POWER, DESCENDED, AND LANDED HARD ON ROUGH/ROCKY TERRAIN. AN EXAM OF THE ENGINE REVEALED THE FUEL NOZZLE STRAINER WAS CONTAMINATED AND BLOCKED WITH SODIUM, AND IT WAS PARTIALLY COLLAPSED. TESTS OF THE NOZZLE REVEALED THAT FLOW RATES WERE BELOW THE MANUFACTURER'S SPECIFICATIONS. THE HELICOPTER WAS BEING OPERATED EXCLUSIVELY IN A MARINE ENVIRONMENT AND THE OPERATOR PERFORMED COMPRESSOR WASH PROCEDURES ON A DAILY BASIS. IN A SERVICE LETTER, THE ENGINE MANUFACTURER PRESCRIBED TURBINE ENGINE COMPRESSOR WASH PROCEDURES WHICH RESULTED IN IMMERSION OF THE FUEL NOZZLE IN CONTAMINATED WASH WATER. THERE WAS EVIDENCE OF SUBSEQUENT INFILTRATION OF WASH WATER INTO THE FUEL NOZZLE STRAINER. THE FUEL NOZZLE STRAINER HAD A LIFE LIMIT OF 2500 HOURS, BUT ACCORDING TO THE MANUFACTURER, IT WAS NOT SUBJECT TO ANY PRIOR ROUTINE INSPECTION REQUIREMENT.

LAX94FA197
FILE NO. 1416 04/18/94 HANAPEPE,HI AIRCRAFT REG. NO. N1103N TIME (LOCAL) - 13:14 HST

Occurrence# 1 LOSS OF ENGINE POWER(TOTAL) - MECH FAILURE/MALF
Phase of Operation HOVER

Findings
1. - FUEL SYSTEM,NOZZLE - FOREIGN MATERIAL/SUBSTANCE
2. - FUEL SYSTEM,STRAINER - BLOCKED(PARTIAL)
3. - MAINTENANCE,SERVICE BULLETINS - INADEQUATE - MANUFACTURER
4. - PROCEDURE INADEQUATE - MANUFACTURER
5. - INSUFFICIENT STANDARDS/REQUIREMENTS - MANUFACTURER

Occurrence# 2 FORCED LANDING
Phase of Operation DESCENT - EMERGENCY

Occurrence# 3 HARD LANDING
Phase of Operation LANDING - FLARE/TOUCHDOWN

Findings
6. - TERRAIN CONDITION - ROUGH/UNEVEN

The National Transportation Safety Board determines that the probable cause(s) of this accident was:
INADEQUATE TURBINE ENGINE COMPRESSOR CLEANING PROCEDURES BASED ON INFORMATION IN THE MANUFACTURER'S SERVICE LETTER, AND LOSS OF ENGINE POWER DUE TO BLOCKAGE OF THE FUEL NOZZLE STRAINER WITH FOREIGN MATERIAL (SODIUM). FACTORS RELATED TO THE ACCIDENT WERE: THE LACK OF A SPECIFIED SERVICE REQUIRMENT FOR INSPECTION OF THE FUEL STRAINER, AND TERRAIN CONDITIONS IN THE EMERGENCY LANDING AREA.

National Transportation Safety Board

Washington D.C. 20594

Safety Recommendation

Date: September 14, 1998
In reply refer to: A-98-109 through -110

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On October 15, 1997, about 1030 mountain daylight time, a Cessna P210N, N731NX, operated by the Sheriff's Department of Mesa County, Colorado, experienced an in-flight electrical fire while cruising at 16,500 feet over Bryce Canyon, Utah. The commercial pilot initiated an emergency descent and landed uneventfully in Bryce Canyon with minor damage. The pilot and his passenger were not injured. Visual meteorological conditions prevailed, and a visual flight rules flight plan had been filed. The public-use flight was conducted under Title 14 Code of Federal Regulations Part 91, and originated from Grand Junction, Colorado, about 60 minutes before the incident.

The Safety Board's investigation revealed that the fire originated on the cabin sidewall, under the left side of the instrument panel, and resulted in burned vinyl, plastic, and insulation material.[1] The fire was caused by an overheated resistor used in an electric door seal inflation system. The resistor was used to reduce the 28-volt aircraft electrical system's voltage to meet the power requirements of the door seal system's 14-volt air pump motor. The system had been installed on the airplane in accordance with a Federal Aviation Administration (FAA)-approved supplemental type certificate (STC)[2] that was issued to the system's manufacturer, Bob Fields Aerocessories, Inc., in 1983. The purpose of the system is to decrease in-flight cabin

[1] Bryce Canyon, Utah, October 15, 1997, Cessna P210N, N731NX (FTW98TA051).
[2] A supplemental type certificate can be issued by the FAA for design changes to type-certificated aircraft when the change is not so extensive as to require a new type certificate for that aircraft. STCs are typically approved for optional after-market kits that improve an aircraft design. The STC applicant must submit sufficient technical data to the FAA to show compliance with the applicable certification requirements.

noise caused by ill-fitting cabin doors. According to Bob Fields Aerocessories, about 20,000 of these systems are currently installed in a wide variety of single- and twin-engine general aviation airplanes.

Since the Bryce Canyon incident in October 1997, the Safety Board has investigated one accident and two incidents that also involved in-flight fires originating in electric inflatable door seal systems manufactured by Bob Fields Aerocessories. Moreover, a review of the FAA's Service Difficulty Report database revealed four additional reports of overheated components associated with the door seal system, three of which cited smoke in the cockpit. A description of the recent accident and incidents investigated by the Safety Board follows.

On November 20, 1997, a Beech 95-B55, N3681K, sustained substantial damage after impacting trees during a precautionary landing in Burlington, Kansas. The landing was precipitated by smoke and an electrical fire in the cabin during cruise flight at 6,500 feet. Postaccident examination of the airplane revealed that a Bob Fields Aerocessories electric door seal inflation pump, mounted on the forward side of the nose bulkhead, was heavily charred. The Safety Board determined that the probable cause of the accident was, in part, "the door seal inflation pump catching fire."[3]

On June 25, 1998, the pilot of a Cessna P210N, N5083W, initiated a precautionary landing in Ithaca, New York, after heavy smoke had entered the cabin during cruise flight at 5,000 feet. Immediately after the landing, airport fire and rescue personnel discovered a self-sustaining fire originating under the left side of the instrument panel. Vinyl, plastic, and insulation material had burned in the fire. Subsequent examination of the airplane revealed that one of the resistors used in the Bob Fields Aerocessories electric door seal inflation system installed on the airplane was partially melted.[4] The Safety Board recently learned of a July 17, 1998, incident aboard a Beech 58 airplane in which the pilot reported a burning smell in the cockpit while in cruise flight. He landed in Toms River, New Jersey, and asked a mechanic to inspect the airplane. The mechanic reported that the pump assembly and resistors for the installed Bob Fields Aerocessories electric door seal inflation system, mounted in the nose compartment, were partially melted.[5]

The electric door seal inflation system manufactured by Bob Fields Aerocessories consists of an electric motor, an air pump, inflatable silicon door seals, a pressure sensing switch, an air supply control valve, a resistor assembly, a 7.5-amperes (amps) in-line fuse, a caution light, and electrical wiring. A 5-amp circuit breaker may also be provided as an option. The motor draws power directly from the airplane's battery bus and is used to inflate the door seals to a pressure of about 10 pounds per

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[3] For more detailed information, see Brief of Accident CHI98LA041 (enclosed).
[4] Ithaca, New York, June 25, 1998, Cessna P210N, N5083W (NYC98SA138).
[5] Toms River, New Jersey, July 17, 1998, Beech 58, N53RD (NYC98SA167).

square inch (psi). A sensor on the air pump determines when the pressure drops below 10 psi, at which time the air pump motor cycles back on until the proper pressure is achieved. According to the STC-holder, it takes between 4 and 12 seconds after system activation for the air pump to inflate the door seal; during this time, the caution light remains illuminated. If the door seal has a small leak, the pump cycles on and off to maintain the desired inflation pressure. If the door seal has a larger leak, the air pump may run continuously to keep the door seal inflated.

The Safety Board's review of the system design revealed that the system incorporates two identical 1-ohm resistors, each rated for a maximum of 50 watts. The resistors are wired close together and in series. According to technical specifications provided by the vendor of the resistor, the resistor's wattage capability should be derated to no more than 20 watts if it is not mounted onto a sufficiently sized conductive structure for heat dissipation. Test data from the vendor further indicate that the aluminum housing of a single resistor will heat up to 313° F when the resistor carries the nominal wattage of the door seal inflation system and is adequately mounted to provide for heat dissipation.[6] The housing temperature rises to more than 600° F if the resistor is not mounted to conductive material for heat dissipation. The potential for overheating is increased by the two resistors being wired closely together.

The Safety Board reviewed the FAA-approved installation instructions for the Bob Fields Aerocessories electric inflatable door seal pump. The instructions state, "...be sure to mount the resistors pak [sic] to a metal plate to make a heat sink. This plate and resistors can be mounted at the parking brake support angle under the instrument panel." No other instructions are found related to the resistor mounting. The investigations into the Bryce Canyon, Ithaca, and Toms River incidents revealed that the resistors were either hanging freely, or were mounted to structure in a manner that was insufficient to dissipate the heat generated by the resistors. The Safety Board is concerned that the installation instructions are insufficient and do not provide enough detail or cautions regarding the proper installation of the resistors and the minimum specifications for a heat sink.

The Safety Board is also concerned about other aspects of the design of the door seal inflation system that can lead to the overheating of the resistors and other system components. The design calls for the system to be installed in confined areas on the aircraft. For example, in the two-door Cessna airplane models, the STC suggests that the system be mounted behind the pilot's "kick panel." The kick panel area is a confined space between the external skin of the airplane just forward of the door and an upholstered panel under the left side of the pilot's instrument panel. This space has limited ventilation and inhibits the cooling required for a continuously

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[6] The door seal inflation system draws a nominal current of 6 amps, thereby producing 36 watts of power through each 1-ohm resistor. Test data indicate that 36 watts of applied power through the specified resistor that is mounted on top of a box-shaped, aluminum chassis for heat conduction (0.040 inch thick, 5 inches wide, 7 inches long, and 2 inches deep) will produce a housing temperature of 313° F.

operating electrical pump and its associated resistors. The space also provides potentially combustible materials in close proximity to heated electrical components, as illustrated by the Bryce Canyon and Ithaca incidents.

Another aspect of the door seal inflation system design that could lead to overheating involves the endurance rating of the electrically driven air pump. According to the vendor that supplies the air pump to Bob Fields Aerocessories, the pump was originally designed to be plugged into an automotive cigarette lighter socket and was intended to be used for the emergency inflation of automobile tires. In a letter forwarded to the Safety Board, the vendor stated that the continuous use of the pump "should not exceed 10 minutes without stopping for 30 minutes" to prevent overheating. The application of the air pump for the pressurization of airplane door seals during flight is inappropriate because the pump may be required to operate for more than 10 minutes, or to run continuously if the door seal leaks. This was illustrated in the Bryce Canyon incident when the caution light was observed by the pilot to be continuously illuminated. The Safety Board is concerned that extended or continuous operation of the air pump will lead to excessive heat buildup, causing an excessive current draw, and will exacerbate the potential for overheating that already exists under the nominal current draw.

Examination of the in-line fuses for the Bryce Canyon, Ithaca, and Toms River incidents revealed that a fuse rated for 10 amps had been installed in the door seal inflation system, exceeding the 7.5-amp-rated fuse specified by the approved STC installation instructions. The Safety Board notes that excessive current draw may result in frequent blown fuses and may prompt the improper installation of a higher-rated fuse. Although the improper use of a 10-amp-rated fuse increases the potential for overheating components, the use of the specified 7.5-amp-rated fuse would not eliminate the hazard because, as discussed above, testing has shown that overheating of the resistors can occur at the nominal door seal inflation system current of 6 amps.

The Safety Board is also concerned that the electric door seal inflation system design does not provide adequate warning of a potential overheat situation. The system incorporates an amber (caution) light on the pilot's instrument panel that illuminates when the pump is operating. The STC installation instructions specify that a placard be placed near the light stating, "CAUTION/DOOR SEAL PUMP ON." However, no information is provided on action to take if the light remains illuminated for an extended period.

The Safety Board concludes that the Bob Fields Aerocessories door seal inflation system design does not provide owners or operators with adequate information about corrective action if the system begins to overheat. Also, it may not become apparent to an operator that the system is overheating until there are indications of an electrical fire. The system design does not incorporate its own electrical cut-off switch; therefore, the pilot's only means to address an overheating system or component is to turn off the airplane's entire electrical power system using the master switch.

The Safety Board is very concerned that these design deficiencies increase the likelihood of an in-flight electrical fire and/or smoke in the cockpit during flight, as evidenced by the accident and incidents discussed above, as well as additional incidents identified by SDRs. Therefore, the Safety Board believes that the FAA should issue an airworthiness directive to require that all owners and operators of airplanes equipped with electric door seal inflation pump systems manufactured by Bob Fields Aerocessories immediately disconnect them from the airplanes' electrical systems. In addition, the FAA should review all STCs that provide for the installation of electric door seal inflation pump systems manufactured by Bob Fields Aerocessories, and require revisions, as necessary, to ensure that the hazards associated with in-flight fire and/or smoke in the cockpit during flight are eliminated. Existing systems should be required to comply with those instructions before they are placed back into service.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Issue an airworthiness directive to require that all owners and operators of airplanes equipped with electric door seal inflation pump systems manufactured by Bob Fields Aerocessories immediately disconnect them from the airplanes' electrical systems. (Urgent) (A-98-109)
>
> Review all supplemental type certificates that provide for the installation of electric door seal inflation pump systems manufactured by Bob Fields Aerocessories, and require revisions, as necessary, to ensure that the hazards associated with in-flight fire and/or smoke in the cockpit during flight are eliminated. Existing systems should be required to comply with those instructions before they are placed back into service. (A-98-110)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 01/30/98

CHI98LA041
FILE NO. 640 11/20/97 BURLINGTON,KS AIRCRAFT REG NO. N3681K TIME (LOCAL) - 08:30 CST

MAKE/MODEL -Beech-95-B55
ENGINE MAKE/MODEL -Continental IO-470-L
AIRCRAFT DAMAGE -Substantial
NUMBER OF ENGINES -2
OPERATING CERTIFICATES -NONE
TYPE OF FLIGHT OPERATION -Personal
REGULATION FLIGHT CONDUCTED UNDER -14 CFR 91

	FATAL	SERIOUS	MINOR/NONE
CREW	0	0	1
PASS	0	0	1

LAST DEPARTURE POINT - ROGERS, AR
DESTINATION - CONCORDIA,KS

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 8.000 SM
WIND DIR/SPEED - 180 /016 KTS
TEMPERATURE (F) - 42
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 39

CERTIFICATES/RATINGS
Private
Single-engine land, Multiengine land
INSTRUMENT RATINGS
Airplane

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT - 1323
LAST 90 DAYS - 38
TOTAL MAKE/MODEL - 201
TOTAL INSTRUMENT TIME - 221

The pilot said they were about 40 minutes into their flight when "my passenger and I heard the pneumatic door seal give way." He recycled the switch, but nothing happened. A few minutes later, the pilot and passenger noticed "the faint smell of electrical burn." The pilot switched the heater off and the smell seemed to subside. He switched the heater back on and noticed a stronger smell immediately. Black smoke began to enter the cabin from above and beneath the instrument panel. The pilot said that as he reached for the throttle, he noticed "that there was orange spark and flame under the panel." He initiated a steep descent and began looking for a place to land. He located a north-south running dirt road, and initiated a 180-degree turn to land. The pilot overshot the road and decided that he didn't have enough altitude and airspeed to maneuver back to the road. He leveled the airplane and landed in a field. During the landing, the airplane encountered uneven (rising) terrain and trees. An exam of the airplane revealed the door seal inflation pump was heavily charred. An exam of the cabin revealed the door inflation seal around the cabin door was missing, both forward air vents were in the open position, and plastic insulation surrounding electrical wiring in front of the right air vent was melted. Melted plastic was observed on the floor, beneath the right side air vent. No other anomaly was found.

CHI98LA041
FILE NO.640 11/20/97 BURLINGTON,KS AIRCRAFT REG NO. N3681K TIME (LOCAL)- 08:30 CST

Occurrence# 1 FIRE
Phase of operation CRUISE

Findings
1. AIR COND/HEATING/PRESSURIZATION - UNDETERMINED
2. EMERGENCY PROCEDURE - NOT PERFORMED - PILOT IN COMMAND
3. ELECTRICAL SYSTEM,ELECTRIC WIRING - MELTED

Occurrence# 2 IN FLIGHT COLLISION WITH OBJECT
Phase of operation EMERGENCY LANDING

Findings
4. PRECAUTIONARY LANDING - MISJUDGED - PILOT IN COMMAND
5. OBJECT - TREE(S)

Occurrence# 3 IN FLIGHT COLLISION WITH TERRAIN/WATER
Phase of operation EMERGENCY LANDING

The National Transportation Safety Board determines the probable cause(s) of this accident was: an undetermined event resulting in the door seal inflation pump catching fire, the pilot's failure to close the cockpit air vents allowing heat and flames from the airplane's nose section to melt electrical wiring behind the instrument panel, and the pilot overshooting the road during his precautionary landing. A factor contributing to this accident was the trees.

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