National Transportation Safety Board

Washington, D.C. 20594

Aircraft Accident Brief

Accident Number:	DCA98MA023
Operator/Flight Number:	American Airlines 1340
Aircraft and Registration:	Boeing 727-223, N845AA
Location:	Chicago, Illinois
Date:	February 9, 1998

HISTORY OF FLIGHT

On February 9, 1998, about 0954 central standard time (CST),[1] a Boeing 727-223 (727), N845AA, operated by American Airlines as flight 1340, impacted the ground short of the runway 14R threshold at Chicago O'Hare International Airport (ORD) while conducting a Category II (CAT II) instrument landing system (ILS) coupled approach.[2] Twenty-two passengers and one flight attendant received minor injuries, and the airplane was substantially damaged. The airplane, being operated by American Airlines as a scheduled domestic passenger flight under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121, with 116 passengers, 3 flight crewmembers, and 3 flight attendants on board, was destined for Chicago, Illinois, from Kansas City International Airport (MCI), Kansas City, Missouri. Daylight instrument meteorological conditions prevailed at the time of the accident.

The flight crew checked in at ORD about 1344 on February 8, 1998, for a scheduled 1444 departure to MCI, the first leg of a 3-day trip sequence. The flight arrived at MCI about 1551, and the crew remained in Kansas City overnight. The flight crew checked in at MCI about 0700 on February 9 for the scheduled 0759 return leg to ORD. After the passengers had boarded, the flight crew was advised by air traffic control (ATC) to expect a 1-hour gate hold because of poor weather conditions at ORD. The flight departed MCI about 0843.

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

[2] The ILS is a precision approach system that provides lateral alignment (localizer) and vertical guidance (glideslope) with the runway. According to the American Airlines Category II Operations Study Guide, CAT II approaches are "straight-in ILS approaches conducted to decision heights [DH] as low as 100 feet above the highest elevation in the touchdown zone, with runway visual range [RVR] less than 1,800 feet, but not less than 1,200 feet." A coupled approach is flown using the autopilot to control the airplane to either a predetermined DH or to a landing, depending on the capabilities of the airplane and the autopilot system. According to the American Airlines 727 Operating Manual, the use of the autopilot to DH is required, and the captain is required to land the airplane after monitoring the first officer's approach and descent to DH. The manual also states that "a good autopilot should fly the airplane down the ILS course with significant precision and smoothness so that the airplane is 'in the slot' at breakout and in trim upon disengagement so that it can be landed without excessive maneuvering."

At 0923:55, while at 33,000 feet, the captain briefed the approach. The briefing included the ORD runway 14R navigation radio frequencies, approach fixes, altimeter settings, crew callouts, and the missed approach procedure. According to the cockpit voice recorder (CVR) transcript, at 0925:22, the captain stated that, after 100 feet, he would "keep it on autopilot just a few seconds and then...and then disconnect." At 0925:42, a Chicago Air Route Traffic Control Center (ARTCC) controller told flight 1340 to descend and maintain 24,000 feet. At 0928:10, the Chicago ARTCC controller instructed flight 1340 to "cross four five [45 nautical miles] southwest of O'Hare one one, eleven thousand."

The flight crew made initial contact with the west arrival controller at the Chicago Terminal Radar Approach Control (TRACON) facility at 0936:51 and advised that they had automatic terminal information service information X-ray, the most current airport weather advisory. The west arrival controller instructed flight 1340 to expect the runway 14R ILS approach and advised the flight crew that the current RVR[3] for runway 14R was 1,600 feet at the runway touchdown point.

The west arrival controller vectored flight 1340 southwest of ORD on a right downwind for runway 14R. At 0948:01, the west arrival controller instructed flight 1340 to intercept the final approach course at an altitude of 5,000 feet. At 0948:32, when flight 1340 was about 18 miles from the airport, the west arrival controller cleared the airplane for the ILS approach to runway 14R and directed the flight crew to maintain an airspeed of 170 knots until reaching ROAMY, the outer marker, located 5.2 distance measuring equipment (DME) miles from the runway threshold. At 0948:39, the flight crew acknowledged the approach clearance. At 0948:49, the west arrival controller again advised the flight crew that the RVR was 1,600 feet at the runway touchdown point. At 0949:08, the west arrival controller advised flight 1340 to contact the ORD tower and to report its position at ROAMY.

At 0952:15, the flight crew contacted the ORD south local tower controller and advised that they were at ROAMY inbound. The controller cleared flight 1340 to land 2 seconds later and advised the flight crew that the winds at runway 14R were calm, with a touchdown RVR of 1,600 feet.[4] At 0952:29, the flight crew acknowledged the landing clearance; this was the last transmission received from the flight crew.

[3] According to the *Aeronautical Information Manual* (AIM), RVR "represents the horizontal distance a pilot will see down the runway from the approach end. It is based on the sighting of either high intensity runway lights or on the visual contrast of other targets, whichever yields the greater visual range. RVR, in contrast to prevailing or runway visibility, is based on what a pilot in a moving aircraft should see looking down the runway. RVR is horizontal visual range, not slant visual range." The AIM further states that touchdown RVR "is a visibility readout...obtained from RVR equipment serving the runway touchdown zone." The touchdown RVR is a determining factor for CAT II approaches; the minimum touchdown RVR for a CAT II approach to runway 14R was 1,200 feet.

[4] The south local tower controller did not instruct flight 1340 to contact the ground controller after landing, as required by Federal Aviation Administration (FAA) Order 7110.65M, "Air Traffic Control Handbook," Section 2-1-17, "Radio Communications Transfer," which states that controllers should "transfer radio communications before an aircraft enters the receiving controller's area of jurisdiction unless otherwise coordinated or specified."

According to the CVR and postaccident pilot statements, the flight crew was executing a monitored approach, which required the first officer to fly the approach and descent to DH and the captain to take the controls at DH and land the airplane. The first officer stated that when flight 1340 was cleared to intercept the localizer (at 0947:44), he selected NAV/LOC on the autopilot. He stated that when they were cleared for the approach (at an altitude of about 5,000 feet), he selected AUTO/G/S (glideslope) on the autopilot and on the flight director. He stated that the autopilot system was tracking the localizer and glideslope normally and that the airplane was configured at 170 knots, with flaps set at 15° until ROAMY, when flaps were extended to 30°, and the airplane was slowed to 143 knots.

During postaccident interviews, the captain told National Transportation Safety Board investigators that at an altitude of 200 feet, the glideslope and localizer were "wired," and that after an instrument scan, he concluded that "everything appeared solid." He stated that he then concentrated his attention outside the cockpit to locate the runway environment. He stated that he saw the lead-in lights "somewhere between 200 feet and DH" and checked his instruments. The captain stated that the lead-in lights were faint but that he could see that the airplane was lined up on the runway centerline. He also stated that when he took control of the airplane, he "wriggled up" in his seat to see the lights better.

The first officer continued to fly the approach until 0953:49, when the captain stated, "I got it," as the airplane descended through 140 feet above ground level (agl). The first officer acknowledged the transfer of control 1 second later. In postaccident interviews, the first officer stated that the captain "clearly took control" of the airplane. The first officer stated that after he made the 200-foot call, and sometime before reaching DH, he felt "a pitch down." He stated that he was concentrating his instrument scan on the radio altimeter and that the autopilot was engaged at this time. He stated that he then looked out the window and saw the approach lights and the "nose pointed short of the runway."

The captain stated that in a "heartbeat" the lead-in lights went from normal to "all around us." According to the captain, he was holding the control column yoke "lightly," and one of his fingers was next to the autopilot disconnect button. He stated that he did not think he pushed the control column forward and that he thought the autopilot "pushed the airplane over." The captain stated that the autopilot remained engaged throughout the cruise and descent phases of flight. He told Safety Board investigators that a lack of horizon cues and what he described as a "low runway light intensity setting" delayed his visual acquisition of the runway environment, and he noted that he wore his sunglasses throughout the descent and approach until touchdown.[5]

According to the CVR, at 0953:51, the flight engineer stated, "ooh nose uh." At 0953:52, the CVR recorded the "sound of a click," consistent with the sound of the autopilot disconnecting, as the airplane was at an altitude of about 80 feet. The captain stated that he did not recall disengaging the autopilot and, that if it was disengaged, it was not done intentionally. At the same time, the CVR recorded the first officer call out, "one hundred [feet]"; a ground

[5] The first officer stated that he removed his sunglasses as the airplane descended through 500 feet.

proximity warning system (GPWS)[6] aural “sink rate” alert; and the flight engineer state, “nose up, nose up.” The captain stated that he then pulled back on the control column. At 0953:54, the CVR recorded a GPWS aural “thirty [foot]” alert and sounds of impact.

The first officer stated that he did not recall hearing a missed approach call; however, he stated that the captain added power and pulled back on the control column to arrest the sink. The flight engineer stated that the captain did not call for a missed approach or advance the throttles to go-around power before impact. He added that he thought that the captain’s actions brought the airplane out of the nose-down attitude and prevented a “solid nose-first strike.” The first officer stated that the airplane “hit harder than a hard landing,” bounced, and hit again. The captain stated that after the first impact he thought, “keep what you got, let’s see if she’ll fly.” He stated that he then felt the airplane bounce, realized that the airplane was on the right side of the runway, and briefly applied left rudder as the airplane skidded down the runway.

Postaccident Landing on Runway 14R and Air Traffic Control Crash Notification

At 0953:44, as flight 1340 was on final approach, the flight crew of a United Airlines (UAL) 737, operating as flight 702, advised the ORD south local tower controller that they were at ROAMY inbound to runway 14R. At 0953:47, the controller cleared flight 702 to land, noting that it was following a 727 (the accident airplane) on 1-mile final. At 0953:55, flight 702 acknowledged the landing clearance.[7] At 0956:17, the tower controller transmitted, “seven oh two [702] United left turn when able ground one two one point nine clear,” and the flight crew acknowledged. At 0957:06, the flight crew of a UAL Boeing 737, operating as flight 754, advised the controller that they were at ROAMY inbound. At 0957:09, the controller cleared flight 754 to land.[8]

According to a transcript of ATC transmissions at the time of the accident, a City of Chicago Department of Aviation vehicle (radio call sign City 149) radioed the tower at 0958:55. City 149 told the tower that “there’s an emergency. There’s a plane down...at fourteen ah right, thirty two left...[and that] there’s debris on the runway at this time.” At 0959:09, the tower controller asked, “on which runway is debris?” At 0959:11, City 149 stated, “fourteen left thirty ah fourteen right thirty two left sir I’m at [taxiway] tee one right now.” At 0959:17, the tower supervisor advised, “ok hold short there’s traffic touching down.” At 0959:21, City 149 replied,

[6] The GPWS warns of a potentially dangerous flightpath relative to terrain. According to the American Airlines 727 Operating Manual, the GPWS installed on the accident airplane operated in the following seven modes: excessive descent rate, excessive terrain closure rate, altitude loss after takeoff or go-around, unsafe terrain clearance, below glideslope deviation, altitude callouts/excessive bank angle callout, and windshear detection. The sink rate alert is a function of the excessive descent rate mode. According to the 727 Operating Manual, this mode “warns of excessive descent rate as a function of radio altitude. Penetrating the sink rate envelope causes the GPWS light to illuminate and a repeated aural alert of ‘SINK RATE’ to be generated.”

[7] The flight crew of UAL flight 702 stated in a National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) report that they flew a monitored CAT II coupled approach to runway 14R and that “the autopilot performed to perfection.” The flight crew report stated that they did not experience any localizer or glideslope anomalies during the approach and that the landing phase after DH and autopilot disconnect was normal.

[8] The flight crew of UAL 754 stated in a NASA ASRS report that their monitored CAT II coupled approach to runway 14R was normal and that they had the runway in sight before they executed a missed approach.

"they can't touch down there's debris all over the place." At 0959:26, the tower supervisor transmitted, "united seven oh two [702] go around ah...united seven fifty four [754] go around." At 0959:43, City 149 inquired, "can I get on the runway at this time?" At 0959:45 the tower transmitted, "no hold short for right now." The City 149 foreman stated that he then witnessed a UAL 737 (flight 754) execute a touch-and-go on the runway. City 149 was subsequently given permission to cross runway 14R and was the first vehicle to arrive at the accident site. At 0959:50, the flight crew of another UAL airplane, operating as flight 400, informed the tower that they were inside ROAMY inbound. The controller advised them to continue inbound on the localizer but to expect to go around.

According to ATC transcripts, UAL flight 702, which landed behind the accident airplane, had contacted the inbound ground controller (IGC) at 0956:49 and was instructed to "turn right on [taxiway] tango alpha seven [TA7] to the ramp." The IGC attempted to contact flight 1340 at 1002:13 and again at 1002:40 but received no response. At 1005:41, the IGC asked the flight crew of UAL flight 49, which was on a taxiway near runway 14R, if they saw "vehicles and an aircraft off [their] right on fourteen right," and the flight crew replied, "yeah there's all kinds of vehicles out here...we don't know the problem out here." At 1005:52, the IGC asked, "you see an aircraft out there?" At 1005:54, an unidentified responder replied, "yeah."

DAMAGE TO AIRPLANE

The airplane was substantially damaged and was later declared a hull loss by the airplane's insurer. According to American Airlines and insurance records, the airplane was valued at $2.3 million.

PERSONNEL INFORMATION

The Captain

The captain, age 42, was hired by American Airlines on June 29, 1984, as a 727 flight engineer. He held an airline transport pilot (ATP) certificate with type ratings in the 727, Douglas DC-9, Fokker-100, and the L-382 (C-130 Hercules). A year later, he transitioned to first officer on the 727. He accumulated about 1,000 hours in the 727 during the next 2 years. He then transitioned to the MD-80, in which he flew as a first officer, and later as captain, accumulating about 2,700 flight hours (1,600 hours as captain) over 4 years. He then became a captain on the Fokker-100, accumulating about 4,000 hours over 6 years. He transitioned to captain on the 727 in April 1997. According to American Airlines records, at the time of the accident, the captain had flown approximately 11,000 total flight hours, of which 424 hours were as a 727 pilot-in-command (PIC).

His most recent FAA first-class medical certificate was issued on January 23, 1998, with no limitations. After completing his 727 initial training, which included crew resource management and unusual attitudes training, he received a type rating on April 10, 1997. His last 727 line check was on April 25, 1997, when he completed his initial operating experience. He also requested and received voluntary recurrent training on September 14, 1997, which included a CAT II approach. According to the captain, he had flown about 10 CAT II approaches in his flying career (or about "once or twice a year"). He stated that the accident flight was his first nonsimulator CAT II approach in a 727.

After the accident, on March 2, 1998, the captain flew CAT II scenarios in a simulator at an American Airlines flight training center. An FAA inspector was present at that time, and the captain was authorized for line operations after the CAT II simulator sessions.

The First Officer

The first officer, age 40, was hired by American Airlines on August 19, 1988. He held an ATP certificate and a type rating for the L-188 (Lockheed Electra). His most recent FAA second-class medical certificate was issued on February 6, 1997, with no limitations. He completed his initial 727 training on November 24, 1990, and his 727 initial operating experience on December 6, 1990. His last proficiency check and recurrent training was completed on October 17, 1997. According to American Airlines records, at the time of the accident, the first officer had flown approximately 5,638 total flight hours, of which 3,731 hours were as a 727 first officer.

The Flight Engineer

The flight engineer, age 40, was hired by American Airlines on November 24, 1992. He held an ATP certificate and a flight engineer certificate with a turbojet-powered rating. His most recent FAA first-class medical certificate was issued on June 24, 1997, with no limitations. His last 727 flight engineer proficiency check was completed on November 4, 1997. His last 727 flight engineer line check was completed on November 22, 1996. According to American Airlines records, at the time of the accident, the flight engineer had flown approximately 1,550 total flight hours as a flight engineer.

The Flight Attendants

The three flight attendants on board flight 1340 had received recurrent training in the 727 in 1997. Flight attendant No. 1, who was assigned to the forward jumpseat and the forward left exit, was hired by American Airlines in 1990 after completing initial training. Flight attendant No. 2, who was assigned to the aft left jumpseat and aft left exit, was hired in 1977 after completing initial training. Flight attendant No. 3, who was assigned to the aft right jumpseat and aft right exit, was hired in 1987 after completing initial training.

The Air Traffic Controllers

The ORD south local tower controller,[9] age 49, was hired by the FAA in 1974 and was first assigned to an FAA facility in Oshkosh, Wisconsin. He transferred to ORD in 1976 as a full

[9] According to FAA Order 7110.65M, Section 3-1-3, "Use of Active Runways," the "local controller has primary responsibility for operations conducted on the active runway" and, therefore, is responsible for determining that the runway will be clear before clearing another aircraft to take off or land. Section 3-10-3, "Same Runway

performance level (FPL) controller, where he worked until resigning from the FAA in 1981. He was rehired by the FAA in 1996 and worked at the Chicago ARTCC for 3 months before transferring to the ORD tower. He received an ORD facility rating in September 1997 and completed a local control checkout on September 10, 1997. In postaccident interviews, he stated that he was assigned to work the south local position for additional facility-required training, which was monitored by the tower operations supervisor.

The ORD tower operations supervisor, age 50, was hired by the FAA in 1976 after attending the FAA training academy. He received FPL status at Palwaukee Airport near Chicago and had FPL status and currency at all positions at the ORD tower. At the time of the accident, he had been a tower operations supervisor for 11 years. He received his ORD facility rating in 1979 and his TRACON rating in 1985.

The tower operations supervisor was monitoring the south local controller in accordance with ORD ATC facility directives, which require that even fully qualified controllers receive a minimum of 10 hours of direct supervision during low-visibility weather conditions. The additional supervision is intended to ensure that controllers can demonstrate the proper use of the airport surface detection equipment (ASDE)-3 surface radar system.[10] According to ATC guidelines, supervisors monitoring controllers during this direct supervision period are responsible for the operation of the controller position and for ensuring that controllers perform their position responsibilities properly. The operations supervisor is also responsible for overall tower operations.[11]

Immediately after the accident, the FAA reassigned the tower operations supervisor to a regional office, decertified the south local controller for a skills check (he successfully completed the skills check and was returned to duty in the tower), and implemented new procedures for low-visibility operations. Among these new procedures was a requirement that controllers cannot permit an airplane to land until they observe the preceding arriving aircraft's "ASDE target" or until "the preceding arriving aircraft has reported clear of the runway."

AIRPLANE INFORMATION

N845AA, a Boeing 727-223, serial number (S/N) 20986, was delivered new to American Airlines on May 15, 1975, and was equipped with three Pratt & Whitney JT8D-9A engines. At the time of the accident, the airplane had accumulated 59,069 flight hours (38,164 flight cycles).[12]

Separation," states that controllers must ensure that an "arriving aircraft does not cross the landing threshold" until the "other aircraft has landed and is clear of the runway."

[10] FAA Order 7110.65M, Section 3-6-1, "Equipment Usage," requires the use of ASDE radar to "augment visual observation of aircraft and/or vehicular movements on runways and taxiways" when visibility is less than "the most distant point in the active movement area." The order adds that controllers should use ASDE surface radar to determine "when the runway is clear of aircraft and vehicles prior to a landing or departure [even after a landing clearance has been issued]."

[11] An FAA memorandum issued after the accident concluded that the supervisor "has been determined to have been responsible for all local actions with regard to the subject accident."

[12] A flight cycle is one complete takeoff and landing sequence.

According to American Airlines maintenance records, a heavy maintenance check (HC) was completed on the airplane on October 23, 1996, at 56,064 flight hours and 36,569 cycles. Three functional flight checks were performed after the HC, and the airplane was released for service on December 11, 1996. One of these functional flight checks included a coupled approach to CAT II minimums, which was the last flight check of the airplane's CAT II system.[13] According to maintenance records, a periodic service (PS) check was completed on the airplane on February 7, 1998. According to the records, no discrepancies involving autopilot, navigation, or flight control systems were found.

According to Safety Board and American Airlines records, the accident airplane was damaged on January 6, 1998, while taxiing. The records stated that the airplane received "substantial damage" after being struck by a moving baggage tug and cart. The collision damaged the airplane's lower left wing, left main landing gear door and wheel well area, left air conditioning bay, lower antennas, left lower fuselage, and several left-wing-trailing-edge and wing-to-body panels. On January 10, 1998, the airplane was ferried to an American Airlines repair facility in Tulsa, Oklahoma, where repairs were completed on January 28, 1998. A functional flight check, which did not include a CAT II check, was performed, and the airplane was released for service.

According to American Airlines maintenance records, N845AA's CAT II status authorization was downgraded 10 times between February 8 and October 21, 1997, because of maintenance discrepancies. No additional CAT II downgrades were logged between October 1997 and the accident date.

Autopilot Information

The airplane was equipped with a Sperry Aerospace[14] autopilot system, which included an SP-50 roll computer, S/N 0681232, and an SP-150 pitch computer, S/N 80060947. The autopilot system controls pitch and roll in all modes of flight. The roll computer receives information from the No. 2 vertical gyro or the navigational system and sends controlling inputs to the airplane's aileron hydraulic servos. The autopilot pitch computer also receives information from the No. 2 gyro and sends signals to the hydraulically powered elevator power control unit. Elevator (aerodynamic) loads commanded by the autopilot are automatically trimmed by the stabilizer trim servo. Autopilot inputs can be overpowered by either pilot (with 20 to 35 pounds of force); however, overpowering the aileron or elevator channels does not cause autopilot disengagement. Pilots can disengage the autopilot electrically by depressing switches on either control yoke.

The autopilot installed on the airplane had not been modified in accordance with changes specified in two Sperry Service Bulletins (SB), SBs 21-1132-121 and 21-1132-122, issued in 1982 and 1983, respectively. The SBs were applicable to SP-50 and SP-150 autopilots and

[13] CAT II landings are not routinely recorded between HC checks and are not required to be recorded as part of the airplane's maintenance program unless there is an anomaly or discrepancy.

[14] Sperry Aerospace was purchased by Honeywell, Inc., in 1988.

recommended a change to the sensitivity schedule of the autopilot while in approach mode to accommodate new, higher approach airspeeds currently in use.[15]

METEOROLOGICAL INFORMATION

Weather observations at ORD were made by an automated surface observing system (ASOS) and augmented by a weather observer. The ASOS for runway 14R was located near the touchdown zone. The weather observer was required to add RVR information to the ASOS observation because of the system's limitations. The weather observer also conducted visibility checks to ensure that the ASOS observations were accurate.

Weather conditions reported at 0956, 2 minutes after the accident, were the following:

> wind from 180º at 4 knots, visibility 1/2 statute mile in freezing fog, ceiling overcast at 100 feet agl, temperature and dew point 28º Fahrenheit, altimeter 30.10 inches of mercury, RVR on runway 14R of 1,400 feet variable to 1,800 feet.

Weather conditions were influenced by a ridge of high pressure over Michigan and a weak pressure gradient over Illinois. A southerly flow of warm moist air prevailed over the cold surface, creating an extensive area of low stratus clouds and fog. The National Weather Service Aviation Weather Center issued an airmen's meteorological information bulletin for an extensive area of instrument flight rules (IFR) conditions throughout the Chicago area because of low ceilings and visibilities. In addition, the Chicago Center Weather Service Unit issued a meteorological impact statement (MIS) at 0715. The MIS called for low IFR conditions with ceilings ranging from 100 feet to 500 feet, improving to higher IFR and marginal visual flight rules conditions after 0900. Conditions began improving at 0938, when visibility increased from 1/4 mile to 1/2 mile.

AIRPORT INFORMATION

ORD is located in Cook and Dupage Counties about 20 miles from downtown Chicago. The airport, owned and operated by the city of Chicago, has 7 runways and 162 gates. The airport has three sets of parallel runways and one nonparallel runway. The parallel runways are 4L-22R/4R-22L, 9L-27R/9R-27L, and 14L-32R/14R-32L. The nonparallel runway is 18-36. Airport elevation is 668 feet mean sea level (msl). The airport has an FAA-approved emergency plan and is certificated as an Aircraft Rescue and Firefighting (ARFF) Index E airport under 14 CFR Part 139.

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[15] For more information, see the section titled, "Autopilot Pitch Sensitivity on Coupled Instrument Landing System Approaches."

Runway 14R General Information

Runway 14R is 13,000 feet long and 200 feet wide. It is the longest runway at ORD, and the approach end is located about 1.71 miles from the control tower. The touchdown zone elevation at runway 14R published on the instrument approach chart was 667 feet msl. The runway threshold elevation was 666 feet msl.

At the time of the accident, runway 14R was equipped with approach light system with sequence flashing lights (ALSF) II, touchdown zone lights, high-intensity runway lights (HIRL), and centerline lights.[16] The ALSF II system includes sequential flashing white lights, rows of high-intensity white lights pointing in the direction of the runway, steady-burning red lights on each side, bars of high-intensity white lights located 1,000 feet and 500 feet from the runway threshold, and threshold lights. The intensities of the ALSF II lights and HIRLs are adjustable.[17] Runway 14R also had runway pavement aiming point markings, comprising two broad, white stripes on each side of the runway centerline, located about 1,000 feet from the landing threshold.

Runway 14R's Instrument Landing System Equipment and Inspections

Runway 14R's ILS/DME instrument approach system comprised a glideslope, localizer,[18] DME, approach lighting system, marker beacons, and compass locators and was approved for CAT I, II, and III approaches. An outer compass locator was collocated with ROAMY.

According to an FAA flight inspection report, a postaccident flight test of runway 14R's Mark 3 ILS system was conducted on February 11, 1998. The test determined that all navigational components, including the glideslope, localizer, and lighting system, were functioning properly. The FAA flight inspection report stated that "glideslope alignment...[and] facility operation [were] found satisfactory."

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[16] According to ATC tower personnel, the intensity of 14R's runway lights was set in accordance with FAA procedures. ATC records indicated that the runway lights were set at Step 5, which is the highest intensity possible and is required for CAT II approaches.

[17] Tower controllers adjust the intensities of the lights based on weather conditions. Pilots can also request that adjustments be made to intensity settings.

[18] The localizer course is usually aligned with the runway. The localizer signal provides electronic angular horizontal displacement information to receivers on the airplane. The glideslope is usually a 3º flightpath to a point about 1,000 feet down the runway from the approach end. The glideslope signal provides electronic angular vertical displacement from the design flightpath angle. The information provided to the pilot on the instrument panel, or directly to the autopilot, indicates whether the airplane should continue on course or fly up, down, left, or right to get back on course. Needle deflections (commonly measured in "dots") on the instruments show how far the airplane has deviated from the localizer or glideslope. For example, 1 dot of needle displacement indicates that the airplane is about 0.32º offset from the 3º glideslope. At the runway threshold, 1-dot fly down would indicate that the airplane was about 6 feet above the glideslope. At the outer marker, 1-dot fly-down would indicate that the airplane was about 200 feet above the glideslope; however, the angular displacement would be the same in both cases. If the airplane were at the outer marker, the pilot or autopilot would have to provide a certain level of elevator input to move the airplane from 1-dot fly down to being "on" the glideslope. However, at the runway threshold, the autopilot would have to provide much less elevator correction for the same 1-dot indication because the actual vertical distance to be corrected is much less.

FAA flight inspection reports indicated that nine flight inspections of the runway 14R ILS were conducted between January 23, 1995, and January 12, 1998; of these, four were periodic inspections and five were special inspections. The flight inspection reports indicated that the localizer was out of service for CAT III operations on November 17, 1997, and that the localizer and the glideslope were out of service for CAT II and III operations on November 18, 1997, because of the presence of heavy construction equipment along the side of the runway (in the ILS critical areas). Normal operations resumed when the equipment was moved away from the runway.

In addition, FAA flight inspection reports indicated that runway 14R's localizer, glideslope, beacon markers, and lighting systems were inspected on January 12, 1998. The inspection included the placement of heavy ground equipment and aircraft at several locations along the left side of the runway and along a parallel taxiway. No anomalies were noted during eight test flights, and the ILS equipment was found to be operating within tolerances.

According to FAA records, the ILS system for runway 14R was taken out of service on September 14, 1998, and replaced with Wilcox Mark 20 ILS equipment, which was operational on September 18, 1998. According to the FAA, the Mark 20 system is based on "a new generation of microprocessors and software," provides "higher reliability and easier maintenance," and has a signal "less susceptible to interference." The replacement project comprised new shelters for the electronic equipment; new glideslope, localizer outer marker, middle marker, and inner marker antennas; and "new electronic equipment for the glideslope, localizer, outer marker, middle marker, inner marker and far field monitors."

After the accident, the FAA also analyzed radio frequency transmissions from a nearby television broadcasting station and transmissions from railroad equipment at a marshalling yard near the end of runway 14R. According to a November 26, 1999, FAA memorandum provided to the Safety Board, its Volpe National Transportation Systems Center's Surveillance and Sensors Division, Office of Traffic and Operations Management, examined the transmissions and concluded the following:

> these signals do not cause radio frequency interference (RFI) to aircraft glideslope receivers using O'Hare runway 14R. In addition, [FAA] Airway Facilities personnel at O'Hare have monitored the glideslope spectrum for approximately one year and have not observed any RFI problems…based on the...information...[RFI] did not and does not exist at…runway 14R's glideslope.

Reported Runway 14R Anomalies

Safety Board investigators examined information from several sources reporting anomalies at runway 14R, including seven pilot debrief records provided by American Airlines. In addition, the Board interviewed several flight crewmembers that reported experiencing glideslope anomalies. For example, an American Airlines captain told Safety Board investigators that he had experienced an anomaly while flying a 727 on an ILS coupled approach to runway 14R at ORD on November 29, 1997. According to the captain and an American Airlines debrief record of the event, he felt a "slight bump" at an altitude of 250 feet. According to the captain, the airplane pitched up slightly when it was slightly below the glideslope, and the glideslope rapidly moved downward, followed by "a fairly severe airplane pitch-over to capture the glideslope." The captain called, "go-around, go-around," added power, and executed the go-around manually. The captain stated that they were in a high rate of descent and that the airplane would have contacted the ground at a high rate of descent and at an extremely nose-low attitude if he had not executed a go-around.

According to the captain, the glideslope deviation was reported to ATC. The captain stated that he thought the anomaly might have been caused by an infringement on the ILS critical area; therefore, he attempted another approach. After experiencing a similar bump at the same altitude, the captain stated that an autopilot go-around was initiated, and the flight diverted to an alternate airport. The debrief record provided by American Airlines did not state what, if any, followup investigation was accomplished, and the cause of this anomaly could not be determined.

Safety Board investigators also interviewed the flight crew of a UAL 737 flight that experienced an anomaly while flying an ILS coupled approach to runway 14R on February 22, 1998. The flight crew stated that they advised approach control that they were going to do an autoland and that approach control stated that it would advise the tower. The flight crew stated that the weather was good but that they were advised by the tower that the ILS critical area was not "clean" (protected) and that a 747 was "rolling." According to the flight crew, the approach was continued until DH (110 feet), when the captain experienced a feeling of sinking accompanied by increased pitch down. The captain stated that he disconnected the autopilot and autothrottles, increased the airplane's pitch attitude to a shallow climb, eased the power back, and landed the airplane manually. The captain stated that he did not note the anomaly in the airplane's maintenance log.

Flight crewmembers from a UAL 737 flight that landed before the accident flight and the flight crews of the two UAL 737 flights that landed after the accident flight were also interviewed by Safety Board investigators. All six flight crewmembers reported stable approaches with no ILS anomalies.

Safety Board investigators also requested data from NASA's ASRS database. The ASRS database search of runway 14R incident reports from January 1, 1988, to the time of the accident found 14 flight crew-reported anomalies. None of the 14 ASRS-reported anomalies indicated glideslope deviations or problems associated with runway 14R's ILS system.

Additional pilot reports of problems (both before and after the accident) with runway 14R's ILS system were received and reviewed by the Safety Board. Most of the reports stated that after the aircraft was established on the glideslope, some sort of disturbance was observed in an otherwise stable glideslope. The disturbances were noticed at various places along the glideslope. Some disturbances were large enough or the aircraft was low enough to the ground that they required the pilots to take immediate corrective action. Some of the reported occurrences could be attributed to aircraft or vehicles moving around the ILS critical area;

however, several of the incidents could not be attributed to any known aircraft or vehicle movement. No pattern to any of the unexplained occurrences was found.

Several of the pilot reports were severe enough that the FAA had requested that a flight check be flown on the ILS 14R to make sure that the system was operating normally. In all of the normal and special flight checks, the ILS system was found to be within normal limits; therefore, the FAA concluded that the pilot-reported incidents were transient events.[19] Additionally, data, such as signal strength, alignment, and symmetry, collected from the FAA flight check aircraft were plotted in real time on a strip chart recorder and analyzed by the Safety Board. Most of the plots show that the aircraft intercepted the glideslope from below. The plots show that once the aircraft became stabilized on the glideslope, minor deviations of the signal occurred. Most of the plots also show a "bump" in the glideslope signal about 2,000 to 3,000 feet from the antenna. The bump is about 15 microamps of signal deviation. This minor deviation of the ideal glidepath is well within the flight check standards used to certify an operational system (75 microamps is required to generate 1 dot of deviation).[20]

FLIGHT RECORDERS

Cockpit Voice Recorder

The airplane was equipped with a Fairchild A-100A CVR, S/N 58463. The CVR's exterior showed no evidence of structural damage, and the interior sustained no heat or impact damage. The recording consisted of four channels of good quality audio information, including the captain's, first officer's, flight engineer's, and cockpit area microphone. The recording started at 0923:12 as the flight crew was preparing to descend from cruise altitude, continued through the approach, and ended at 0954, shortly after the airplane impacted the runway and lost electrical power. A transcript was prepared of the 31-minute recording.

Flight Data Recorder

The airplane was equipped with a Sundstrand Universal flight data recorder (FDR) model 980-4100-GXUS, S/N 4699. The 11-parameter FDR was configured to record 15 channels of information, including pressure altitude, calibrated airspeed, pitch angle, roll angle, magnetic heading, longitudinal acceleration, vertical (and/or normal) acceleration, elevator position, engine pressure ratio (EPR) for all three engines, and very high frequency radio microphone keying.

The readout of elevator position sensor data and longitudinal load factor data determined that the data were not representative of typical or expected values and were considered erroneous. The elevator sensor was removed from the airplane, tested, and found to be operating normally. The FDR signal outputs for the longitudinal acceleration and elevator position sensors were tested and found to be operating normally. No other FDR discrepancies were found.

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[19] Additionally, when a pilot would report an anomaly, the aircraft that flew the approaches before and after the incident aircraft had normal ILS indications.

[20] This deviation of the glideslope signal would be measured by the sensitive flight check instrumentation but would not be discernable to the pilots during the approach.

A subsequent Safety Board examination of the airplane's FDR maintenance history determined that a supplemental type certificate (STC) used to modify the FDR in 1993 contained a wiring anomaly. The STC modified the FDR to add five parameters, including elevator position, roll attitude, pitch attitude, engine EPRs, and longitudinal acceleration. It was determined that the STC wiring requirements did not properly differentiate elevator position parameters generated by two independent hydraulic power units (system A and system B), which were part of the autopilot control system.

The FDR received elevator position signals from the system that was selected by the flight crew on the cockpit autopilot control panel. The accident flight crew had selected system B. Examination of the wiring determined that when system A was selected, elevator data were recorded correctly and that when system B was selected, the data were erroneous. A review of maintenance records determined that American Airlines maintenance work card 5404 called for system A to be selected during ground tests using a data signal display unit (DSDU).

According to American Airlines' FAA-approved maintenance program, a functional check of the FDR system is required every 3,200 flight hours. The accident airplane's FDR system was checked during a maintenance check on November 7, 1997.[21] Maintenance records indicated that all FDR parameters were working properly. The DSDU displays recorded FDR data in binary and octal formats. Because the STC assumed that display tolerances would be the same for both systems, no ground tests were conducted for system B.[22]

In addition, a Safety Board examination of the FDR's biaxial accelerometer, which measures vertical and longitudinal acceleration, determined that the unit had been incorrectly mounted and was not recording expected data values. The examination determined that labels indicating correct positive y-axis (longitudinal) and positive z-axis (vertical) unit positioning were affixed to the top of the unit 90° from their proper position. The incorrect label positioning resulted in the unit, which is mounted in the left main landing gear wheel well, being mounted 90° from its proper position, causing the longitudinal acceleration sensor (y-axis) to measure lateral acceleration rather than longitudinal acceleration. Longitudinal data would have yielded information about the airplane's deceleration at impact.[23] Further testing determined that the accelerometer unit functioned properly when positioned correctly. The mislabeling and subsequent incorrect mounting did not affect the vertical accelerometer parameter.[24]

[21] According to American Airlines maintenance records, the FDR was overhauled on February 6, 1997, and installed on the accident airplane on May 18, 1997.

[22] The STC holder, Flight Systems Engineering, Miami, Florida, issued an SB on August 8, 1998, to correct the wiring anomaly, and modifications were made to 56 American Airlines 727s to correct the problem.

[23] A Safety Board examination of the 5404 work card from the accident airplane's November 7, 1997, maintenance check indicated that the FDR display reading for longitudinal acceleration was not in the required display tolerance range for the DSDU test and that this discrepancy was not noted.

[24] The Safety Board has issued several safety recommendations related to FDR maintenance checks, FDR systems documentation, and FDR maintenance recordkeeping. For example, as a result of its investigation into the crash of a Douglas DC-8-61 in Miami, Florida, in 1997, the Board issued Safety Recommendations A-98-53 and -54. Safety Recommendation A-98-53 asked the FAA to require "an immediate readout of all 11-parameter retrofitted FDRs to ensure that all mandatory parameters are being recorded properly"; to ensure that the FDR system

WRECKAGE AND IMPACT INFORMATION

Ground scars indicated that the airplane touched down 160 feet short of the runway pavement (314 feet from the runway's displaced threshold), became airborne, touched down again on the runway, and then slid about 2,350 feet down the runway until coming to rest in an upright position in the mud about 250 feet to the right (west) of the runway. The two main landing gears and parts of the airplane's lower aft section and left and right wings were found along a 2,670-foot debris path, beginning before the runway threshold and ending where the airplane came to rest. The nose landing gear was found rotated aft into the electrical/electronics (E/E) compartment. The pneumatic start connection door and the lower tail skid assembly from the aft fuselage were found 180 feet from the runway threshold. The airstairs, airstairs door, right spoiler panels, flap surfaces and control assemblies, landing gear fairings, access doors, and landing gear parts from all three landing gears were found along the debris path. The bottom of the fuselage sustained substantial damage from the nose to the empennage. The bottom of the left and right wing surfaces, including the flight control surfaces, were found torn, dented, or scratched. The fuselage skin was torn from the nose landing gear wheel through the E/E compartment, and the nose gear strut assembly was found rotated into the E/E compartment. The airplane's main electrical wiring bundles were found torn and loose in the E/E compartment, and the electronics (avionics) racks were dislodged from their attach points.

The airplane was found configured for a normal approach in instrument conditions. The gear was extended, flaps were set at 30°, and the leading-edge slats were extended. The right inboard flaps and right inboard spoiler were fractured at their attach points on the inboard side near the fuselage. Vertical tears and dents in the fuselage were found above the right wing root and over the attachment points of the right main landing gear. Multiple scrapes, bends, and dents were found on the flaps and slats. Earthen debris was embedded in the slats. The trailing-edge flaps were found with scrapes and bends along their trailing edges. The ailerons were found intact with minor damage, with the left aileron trailing edge up and the right aileron trailing edge down. The cockpit column yokes were in the left-roll position. The horizontal stabilizer was in the 6° nose-up position and matched the setting position in the cockpit. The elevators were found intact with no damage. The lower rudder was fully deflected to the left, and the upper and lower trim surfaces were deflected to the left. All of the airplane's systems positions matched the cockpit command positions. Safety Board investigators documented the following autopilot

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documentation "is in compliance with the range, accuracy, resolution, and recording interval specified in 14 [CFR] Part 121, Appendix B"; and to require that the "readout be retained with each airplane's records." Safety Recommendation A-98-54 asked the FAA to require maintenance checks of FDRs on transport-category aircraft "every 12 months or after any maintenance affecting the performance of the FDR system, until the effectiveness of a proposed advisory circular and new FAA inspector guidance on continuing FDR airworthiness (maintenance and inspections) is proven" and to require that air carriers attach to the maintenance job card "a computer printout, or equivalent document, showing recorded data, verifying that the parameters were functioning properly during the FDR maintenance check and [to] require that this document be part of the permanent reporting and record-keeping maintenance system." On January 11, 2000, the Board classified Safety Recommendations A-98-53 and -54 "Open—Acceptable Response."

settings on the autopilot console in the cockpit: MAN, roll knob centered, AIL and ELEV OFF, B Mode, ALT and HDG OFF.[25]

Examinations of the left (No. 1), center (No. 2), and right (No. 3) engines revealed no evidence of an in-flight fire or a fuel leak. FDR data indicated that the engines were operating normally throughout the approach until they impacted terrain.

SURVIVAL ASPECTS

An emergency evacuation was initiated after the airplane came to a complete stop. During the impact sequence, a ceiling stowage compartment door[26] dropped down and blocked the forward entry door and partially blocked the forward galley door, preventing passengers and crewmembers from exiting the airplane through the forward left exit. Passengers and crewmembers evacuated the airplane through the forward right, aft right, and aft left exit doors and also through the four overwing exits. Twenty-two passengers and one flight attendant reported that they received minor injuries during the accident[27] and subsequent emergency evacuation.[28]

Emergency Response

A UAL van driver who had stopped on a service road near runway 14R witnessed flight 1340 veer off the side of runway 14R. He drove to nearby airport gate security post No. 2 to report the accident. He stated that he arrived at the post about 0958 and informed a security officer, who called the Operations Command Center (OCC). About the same time, City 149, which was also near the No. 2 security post, called the south tower frequency about the accident.

The OCC immediately dispatched police and ARFF units to the scene and paged the deputy commissioner of airport operations, who stated that he arrived at the accident about 3 minutes after receiving the page. The Chicago Fire Department Airports Emergency Medical Systems field officer stated that he was not notified by the tower, as was customary, but heard the OCC notification over "the firehouse speaker." He stated that fire department personnel arrived at the accident scene 2 minutes after receiving notification, about 1000.

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[25] When the autopilot is engaged, the switches are held in position electrically. If electrical power is interrupted or lost, the switches move to the OFF position.

[26] The ceiling stowage compartment door was installed directly above the center aisle on the ceiling of the cabin and was normally used to store liferafts.

[27] Two passenger seat belt attachments became unhooked at impact for undetermined reasons, causing minor injuries to one passenger.

[28] As a result of this investigation, on February 19, 1999, the Safety Board issued Safety Recommendations A-99-10 and -11 to the FAA. Safety Recommendation A-99-10 asked the FAA to "identify all airplanes operated under Title 14 [CFR] Part 121 with liferaft ceiling stowage compartments or compartments that formerly stored liferafts that open downward and issue an airworthiness directive to limit the distance that those compartments can open." Safety Recommendation A-99-11 asked the FAA to "reexamine the design of seatbelts installed on passenger seats on air carrier, air taxi, and commercial airplanes to determine the reason some have become unhooked from their seat attachments during turbulence or a hard landing and establish a suitable means of ensuring that the seatbelts remain attached to their shackles during all modes of flight." On June 2, 1999, the Board classified Safety Recommendations A-99-10 and -11 "Open—Acceptable Response."

ORD's assistant chief operations supervisor stated that he received notification of the accident at 0958 and that he immediately dispatched operations personnel to the accident scene. The airport operations supervisor, who was on patrol on the north end of the airport, was notified and arrived at the accident site about 0959, followed by additional operations personnel about 1000.

A Chicago Fire Department vehicle (CFD 299) attempted to contact the tower at 1000:08 but did not receive an immediate response because the tower controller was issuing missed approach instructions to the flight crew of UAL flight 754. The lead Chicago Fire Department vehicle, call sign CFD 655, contacted the tower at 1000:53 and requested permission to access runway 14R. The south local controller approved the request 2 seconds later. ATC transcripts also indicated that CFD 655 and another ARFF vehicle, CFD 298, made several calls on frequency 119.25 but were not successful.[29] ATC logs indicated that CFD 655 attempted to reach the ground controller on this frequency until 1000:37, when CFD 655 switched to the south local tower frequency. According to ATC logs, there was no communication between the ground controller and ARFF units on frequency 119.25 until 1011:25.

TESTS AND RESEARCH

Airplane Performance

The Safety Board conducted an airplane performance study based on the following combined data and evidence: ground impact scars and markings, airport surveillance radar data, FDR and CVR information, and weather data.

FDR data indicated that the approach was normal until about 9 seconds before impact, when the airplane pitched up from about 0.5° to about 3.5°. About 5 seconds before impact, the pitch attitude was about -2°. The airplane's pitch attitude continued to decrease to -6° 2 seconds before impact, coincident with a full-scale, below glideslope instrument deflection about 60 feet agl.

According to FDR data, at the time of impact, the airplane's pitch angle was about 5° nose up, and the airplane's bank angle was about 5° right wing down. The pitch and bank angles were consistent with ground impact markings that indicated that the right main landing gear struck the ground first. The Safety Board's airplane performance study indicated that the airplane's flightpath angle was about -5° and that the angle-of-attack was between 10° and 11° at the time of impact. FDR data indicated a descent rate of 1,350 feet per minute, a ground speed of 133 knots, and a true airspeed of 142 knots at the time of impact.

[29] Frequency 119.25 is a tower frequency dedicated to ARFF services. The tower operations supervisor told Safety Board investigators that the frequency was not being monitored at the time of the accident, although tower procedures require it to be monitored. After the accident, ground controllers were instructed to monitor the frequency.

FDR data indicated that vertical acceleration values were about 1.0 g[30] for most of the 5 minutes before the data ended. Values began increasing at 0953:46 to a maximum of 1.183 g's and then decreased to 0.732 g, before increasing to 1.618 g's by 0953:53. A 3.8-g spike also occurred at a time that is consistent with the airplane's impact with the ground.

Because FDR data did not record stabilizer positions and because the recorded elevator positions were unusable, it was not possible for the performance study to examine elevator and stabilizer control surface deflections that influenced the airplane's performance during the final approach.

Postaccident Autopilot and Navigation Equipment Testing

The accident airplane's autopilot and navigational equipment (including the air data computer, yaw damper coupler, roll computer, pitch computer, very high frequency omnidirectional radio range/ILS navigational receivers, radio altimeter, autopilot accessory unit, and marker beacon receiver) were reinstalled in the E/E compartment of a similar 727 and tested at an American Airlines maintenance facility in Tulsa, Oklahoma, on May 14, 1998. A complete American Airlines 727 autopilot maintenance test was performed and was similar to a check designed to qualify the airplane for the lower minimums program (LMP) that allowed the airplane to be flown to CAT II minimums. All LMP checks used test ILS and marker beacon signals generated outside the airplane and followed normal test checklist procedures. The autopilot system was tested throughout a coupled CAT II approach procedure, including desensitization of the glideslope gain from 100 percent to about 25 percent and to about 5 percent after the middle marker. The timing of the desensitization was consistent with the design requirements of the original, unmodified version of the SP-150 autopilot.

The testing indicated that the airplane's navigational and autopilot control systems functioned normally and met test parameters for CAT II approaches. The Sperry SP-150 autopilot components were also bench tested at Honeywell's facility in Seattle, Washington, and were found to be operating properly and within prescribed tolerances.

Autopilot Pitch Sensitivity on Coupled Instrument Landing System Approaches

On a coupled ILS approach, the autopilot issues pitch and roll control commands to keep the airplane centered on the glideslope and localizer beams. The magnitude of the pitch and roll commands depends on the magnitude of the deviation from the center of the beams (that is, the error signal) and autopilot sensitivity. The appropriate autopilot sensitivity is determined by the distance from the runway, but there is no direct way to measure this distance if the ILS does not provide DME information. Therefore, to properly set, or schedule, the sensitivity, the distance from the runway must be estimated based on other measurable parameters. One method of estimating distance from the runway is to continually use radio altitude and the geometrical relationship between altitude and distance for an approximately 3° glideslope. As the radio altitude decreases, the airplane is assumed to be closer to the runway, and the autopilot sensitivity

[30] A g is a measure of force on a body undergoing acceleration as a multiple of the force imposed by its mass.

is reduced appropriately. This method will be in error when the terrain preceding the threshold has significant peaks or valleys or if the glideslope differs significantly from the 3° or other angle assumed by the method. However, the method is not affected by the ground speed of the airplane.

Another method to estimate the distance from the threshold is to measure the time elapsed since passing a point of known distance from the runway and then to calculate the distance traveled from that point by multiplying the measured time by an assumed ground speed. This time-based method was used by the Sperry SP-150 autopilot installed on the accident airplane. Although the SP-150 was capable of scheduling the sensitivity based on radio altitude, the accident airplane's autopilot system was configured to start desensitizing over a 150-second period after passing through 1,500 feet radio altitude on the approach. During the 150 seconds, the autopilot sensitivity, or gain, would be reduced from a value of 1.0 to a value of .22 (or about 78 percent). After receiving the signal from the middle marker (located about .5 nautical mile from the runway threshold), the gain further reduced to a value of .055 over 30 seconds (or another 75 percent). If the middle marker signal is received before the gain reaches a value of .22 (that is, before the 150 seconds elapse), the gain will decrease at twice the original rate until reaching .22 and then continue to decrease to .055 over 30 seconds.

A characteristic of the time-based method of desensitizing the autopilot is that the gain will be scheduled properly only if the distance from the runway at 1,500 feet radio altitude is consistent with a 3° glideslope and if the actual ground speed is relatively close to the ground speed the autopilot designers assumed when selecting the time period required for desensitization. If the actual ground speed is higher than the ground speed assumed in the autopilot design, the airplane will approach the runway before the desensitization period expires, and the sensitivity will be higher than that intended by the design. If the actual ground speed is lower than the ground speed assumed in the design, the autopilot will be desensitized while the airplane is still far from the runway, and the sensitivity will be lower than that intended by the design. The ground speed in the SP-150 autopilot design assumed that an airplane on a 3° glideslope would travel from 1,500 feet agl to the middle marker in 150 seconds. Calculations based on FDR data indicated that the accident airplane actually traveled this distance in about 100 seconds. As a result, during the approach, the autopilot sensitivity was consistently higher than its intended design value.

As previously mentioned, during the investigation of this accident, Safety Board investigators determined that the accident airplane's autopilot had not been modified in accordance with changes specified in two Sperry SBs applicable to SP-50 and SP-150 autopilots that recommended a change to the sensitivity schedule of the autopilot while in approach mode to accommodate new, higher approach airspeeds currently in use. The 150-second desensitization period used by the Sperry SP-50 and SP-150 autopilots was originally optimized for approach airspeeds corresponding to a 40°-flap setting. However, in the early 1980s, operators began using a 30°-flap setting and correspondingly higher airspeeds to improve the maneuverability of the airplane during the approach. The changes outlined by these SBs were designed to reduce the time required for autopilot desensitization from 150 seconds to 105 seconds.[31]

Engineering Simulations of Autopilot Pitch Sensitivity

Safety Board investigators conducted 727 engineering simulator studies at Boeing Company facilities in Renton, Washington, to determine the stabilizer and elevator movements required to reproduce the motions of the accident airplane and to evaluate autopilot performance during a coupled ILS approach using the 150-second and 105-second sensitivity schedules in conditions similar to those of the accident flight.

The 727 engineering simulator uses mathematical models of the airplane's aerodynamics, mass properties, and propulsion and flight control systems, together with models of the earth's gravity and atmosphere, to compute the trajectory and orientation of the airplane and its response to engine and flight control inputs. The simulator also contains mathematical models of the airplane's autopilot systems, which duplicate actual autopilot commands. The simulation incorporates these commands into its flight control models to compute control surface deflections and the resulting airplane motion.

Safety Board investigators estimated the stabilizer and elevator movements during the accident scenario using information from the 727 engineering simulator and trim-in-motion sounds from the accident airplane's CVR. To examine how the autopilot responded in returning to and maintaining the glideslope, several methods, such as initially trimming to glideslope angles other than 3° and inducing turbulence or vertical wind gusts, were used to "disturb" the airplane from the glideslope centerline.

[31] As a result of these findings, on June 1, 2000, the Safety Board issued Safety Recommendations A-00-41 through -45 to the FAA. Safety Recommendation A-00-41 asked the FAA to "require operators of…727 aircraft equipped with Sperry SP-50 and SP-150 autopilots to perform the modifications described in Sperry SBs 21-1132-121 and 21-1132-122 if these 727 aircraft are used for coupled ILS CAT II approaches at flap settings less than 4°." Safety Recommendation A-00-42 asked the FAA to "develop sets of operating limitations for the SP-50 and SP-150 autopilots on coupled ILS approaches that are appropriate for the desensitization schedules used by these autopilots so that every possible desensitization schedule has a corresponding set of operating limitations. The limitations should address approach flap settings and airspeeds specifically, and should also consider tolerances on winds, capture altitudes, glide slope angles, and/or other parameters that could adversely affect autopilot performance and safety of flight." Safety Recommendation A-00-43 asked the FAA to "advise all operators of …727 aircraft equipped with SP-50 and SP-150 autopilots to inform their pilots, maintenance, and engineering personnel of the dangers of conducting coupled ILS approaches at airspeeds that are not consistent with the desensitization schedule of the autopilots, and notify the operators that the FAA has been asked to develop operating limitations for the use of these autopilots on coupled approaches that will ensure that the approaches are conducted in a manner consistent with the autopilot design." Safety Recommendation A-00-44 asked the FAA to "review the certification of all autopilot systems that use time-based desensitization schedules and develop operating limitations, as necessary, for the use of these autopilots on coupled ILS approaches. The limitations should address approach flap settings and airspeeds specifically, and should also consider tolerances on winds, capture altitudes, glideslope angles, and/or other parameters that could adversely affect autopilot performance and safety of flight." Safety Recommendation A-00-45 asked the FAA to "advise all operators of aircraft equipped with autopilot systems that use time-based desensitization schedules to inform their pilots, maintenance, and engineering personnel of the dangers of conducting coupled ILS approaches at airspeeds that are not consistent with the autopilot desensitization schedule, and notify the operators that the FAA has been asked to develop operating limitations for the use of these autopilots on coupled approaches that will ensure that the approaches are conducted in a manner consistent with the design of the autopilot."

The simulator results indicated that at the approach speeds of the accident flight, the autopilot with the 150-second desensitization period responded to the disturbances by commanding oscillatory pitch changes that increased over time and resulted in significant deviations from the desired flightpath. The altitude response computed by the simulator in these cases was similar to that recorded by the accident airplane's FDR. The engineering simulator tests also indicated that autopilots with the 105-second desensitization period also commanded divergent oscillatory pitch changes, although these diverged at a slower rate and with less magnitude than those produced during the 150-second period. The simulations also determined that resulting altitude deviations with the 105-second period were smaller than those produced with the 150-second period.

ADDITIONAL INFORMATION

American Airlines Pilot Experience and Training Requirements for CAT II Approaches

American Airlines requires pilots to have completed a CAT II training program and to have accumulated 300 hours as PIC with the airline and 100 hours as PIC in the airplane type to conduct CAT II approaches. Pilots must also be certified by an FAA inspector or designated company check airman to conduct CAT II approaches.

The FAA-approved CAT II training program conducted by American Airlines includes ground and flight training for captains and first officers. The ground training includes information on airborne and ground-based CAT II equipment (including runway lighting and markings), operational rules and limitations (including missed approaches, determination of DH, visual cues, and windshear, as outlined in the American Airlines Flight Manual Part 1, Approach and Landing), and minimum equipment list requirements. The flight training includes initial proficiency requirements, and captains must demonstrate one ILS coupled approach to 100 feet followed by a landing and one ILS coupled approach to 100 feet followed by a missed approach. Captains and first officers must also demonstrate proficiency in CAT II maneuvers during annual recurrent training.

American Airlines Autopilot Procedures

American Airlines 727 Operating Manual requires flight crews to "closely monitor the autopilot system for proper operation and to ensure that proper altitudes are being maintained. Caution must also be exercised at low altitudes to prevent airplane malfunctions from distracting crewmembers' attention from the primary duty of flying the airplane and monitoring flight instruments and the flight profile." The Operating Manual also states that the minimum altitude for the use of the autopilot on ILS coupled approaches is 80 feet and, that on final approach, a callout should be made by the flight engineer, or any crewmember, who at any time observes a "LOC displacement greater than 1/3-dot, and/or GS displacement greater than 1/2-dot" on the captain's and first officer's course deviation indicators (CDI). According to the manual, the pilot flying "will acknowledge this deviation." The glideslope pointer on each CDI points to a fixed scale delineated with a horizontal line and dots. The horizontal line represents the airplane's position relative to the glideslope, and 2 dots above the line and 2 dots below the line indicate the magnitude of the airplane's deviation below or above the glideslope, respectively. A similar pointer is on the horizon director indicator on each instrument panel.

American Airlines CAT II Approach Procedures

According to the American Airlines 727 Operating Manual, CAT II approaches are to be flown with the autopilot coupled to the ILS until DH, and the CAT II procedure requires the captain and the first officer to monitor the autopilot and flight instruments, with the first officer as the flying pilot. The first officer "remains on instruments throughout the approach and landing, and makes all normal callouts below 1,000 feet." Crew coordination procedures cited in the Operating Manual also require the pilots to "monitor marker beacon receiver to verify middle marker for G/S [glideslope] desensitization."

The Operating Manual states that when the captain is ready to take control of the airplane and complete the approach visually, he will "push the first officer's hand from throttles and call out, 'I've got it,' indicating intention to land." If visual contact with the runway is lost or a missed approach is required, "the captain will execute the missed approach procedure. If the approach is continued, the first officer will continue to make all standard callouts (altitudes, sink rate, and localizer/glideslope deviations)."

According to the Operating Manual, if any of the following conditions occur before DH, a missed approach is required:

- Any of the required airplane or ground equipment fails.
- [By DH] The captain has not established sufficient visual references with the CAT II lighting system to safely continue the approach by visual reference alone.
- The captain has not assumed control (first officer executes go-around).
- [Below DH] The captain loses visual reference with the CAT II lighting system or a reduction in visual reference occurs, which prevents the captain from safely continuing the approach by visual reference alone.
- The captain determines that a landing cannot be safely accomplished within the touchdown zone.

Further, according to the Operating Manual, the following procedures should be followed to execute a missed approach:

- Push throttles forward and call out - "Go Around."
- Check GO-AROUND annunciator illuminated green and rotate to a minimum of 10° nose-up attitude with A/P [autopilot] turn knob.

- Execute missed approach procedure.

Stabilized Approach Concept

According to the American Airlines 727 Operating Manual, the stabilized approach concept requires that "before descending below the specified minimum stabilized approach altitude, the airplane should be in the final landing configuration (gear down and final flaps) on approach speed, on the proper flight path and at the proper sink rate, and at stabilized thrust." The Operating Manual adds that "these conditions should then be maintained throughout the rest of the approach."

Information on Visual Cues/Illusions

According to the FAA AIM, Section 8-1-5, "Illusions in Flight," dated February 24, 2000, many different visual illusions experienced in flight can lead to spatial disorientation, landing errors, and accidents. For example, section 8-1-5, Subsection 3, "Illusions Leading to Landing Errors," states the following:

> Various surface features and atmospheric conditions encountered in landing can create illusions of incorrect height above and distance from the runway threshold. Landing errors from these illusions can be prevented by anticipating them during approaches, aerial visual inspection of unfamiliar airports before landing, using electronic glide slope or VASI [visual approach slope indicator] systems when available, and maintaining optimum proficiency in landing procedures.
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> Section 8-1-5, subsection 3, describes atmospheric illusions as follows:
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> Rain on the windscreen can create the illusion of greater height, and atmospheric haze the illusion of being at a greater distance from the runway. The pilot who does not recognize these illusions will fly a lower approach. Penetration of fog can create the illusion of pitching up. The pilot who does not recognize this illusion will steepen the approach, often quite abruptly.

ANALYSIS

The flight crew was properly certificated and qualified in accordance with applicable Federal regulations and company requirements.

The flight crew had received current and adequate weather information before conducting a Category II (CAT II) instrument landing system (ILS) coupled approach, without autoland capability, to runway 14R.

Daylight instrument meteorological weather conditions prevailed at the time of the accident, and, during the approach, were at or above published Federal Aviation Administration (FAA) and airline weather minimums and included a visibility of 1/2 statute mile in freezing fog, an overcast ceiling of 100 feet above ground level (agl), and a runway visual range on runway 14R of 1,400 feet variable to 1,800 feet.

The airplane was properly certificated and equipped in accordance with Federal regulations and approved procedures.

The captain, who was the flying pilot during the final approach, left his sunglasses on during the approach and landing, increasing the potential for visual illusions as a result of reduced visibility.

Analysis of the flight data recorder (FDR) data indicates that the initial portion of the approach (until about 9 seconds before impact) was uneventful and stabilized down to the middle marker. The flaps were set at 30°, and the autopilot was engaged. Two seconds after passing over the middle marker, at an altitude of about 170 feet agl, the airplane deviated to about 1/2 dot below the glideslope before the autopilot corrected it back toward the glideslope. The airplane pitched up from about 1° nose up over the middle marker to about 3.5° nose up 3 seconds later. During the next 3 seconds, the airplane descended to about 140 feet agl and deviated to about 1/2 dot above the glideslope while pitching down to -2°. Immediately after this, the captain stated, "I got it." During the next 2 seconds, the airplane continued to pitch down to about -6° and descended well below the glideslope. During this period, the flight engineer stated, "ooh nose uh," and the captain did not disengage the autopilot or take any action to adjust the pitch attitude.

While flying inside of the middle marker during the most critical phase of the approach at the decision height, the flight crew did not react in a proper and timely manner to excessive pitch deviations and descent rates by either initiating a go-around or adjusting the pitch attitude and thrust to ensure a successful landing, as required by the CAT II procedures outlined in the American Airlines 727 Operating Manual.

As the airplane continued to descend through about 80 feet agl at a nose-down pitch attitude of about -6°, the captain disengaged the autopilot; the first officer called out, "one hundred [feet]"; the ground proximity warning system made an aural "sink rate" alert; and the flight engineer stated, "nose up nose up." These actions all occurred within 1 second as the descent rate rapidly increased to about 1,900 feet per minute. The captain immediately pitched the airplane up to about 6° and added a substantial amount of power. These actions were not sufficient or timely enough to arrest the descent, and the airplane continued to descend until it impacted the ground 314 feet short of the runway threshold, resulting in the separation of the main landing gear. The airplane then became airborne, touched down again on the runway, and then slid about 2,350 feet down the runway until coming to rest in an upright position in the mud about 250 feet to the right (west) of the runway.

Examination of the airframe, engines, and systems did not reveal any preexisting mechanical or electrical malfunctions. FAA flight checks flown on the ILS 14R, analyses of pilot debrief records, and its long-term monitoring of the ILS and surrounding radio frequency transmissions did not reveal any evidence of radio frequency interference (RFI) to aircraft glideslope receivers using the accident runway. The Safety Board also conducted a dedicated study of the 14R ILS and found no evidence of RFI or other system anomalies that would have significantly affected the glideslope receiver and autopilot. According to air traffic control (ATC) records and personnel statements, the runway lights were set at the highest intensity possible, and no evidence was found to suggest otherwise.

The Sperry Aerospace SP-150 autopilot installed on the accident airplane used a time-based method to reduce the autopilot's sensitivity to localizer and glideslope deviations as the airplane approached the runway threshold on the ILS. However, the time-based method used by the SP-150 autopilot assumed that an airplane on a 3° glideslope would travel from 1,500 feet agl to the middle marker in 150 seconds. This time period was based on approach airspeeds corresponding to a 40°-flap setting; however, in the early 1980s, operators began landing Boeing 727s at a 30°-flap setting and correspondingly higher airspeeds to improve maneuverability during the approach. The accident airplane's autopilot had not been modified in accordance with changes specified in two Sperry Service Bulletins (SB), SBs 21-1132-121 and 21-1132-122, issued in 1982 and 1983, respectively, which recommended reducing the time required for autopilot desensitization from 150 seconds to 105 seconds to accommodate higher approach airspeeds.

Calculations based on FDR data indicated that the accident airplane traveled from 1,500 feet agl to the middle marker in about 100 seconds. As a result, during the approach, the autopilot sensitivity was consistently higher than its intended design value. Engineering simulator studies revealed that at the approach speeds of the accident flight, the autopilot (with the 150-second desensitization period) commanded oscillatory pitch changes that increased over time and resulted in significant deviations from the desired flightpath. The investigation revealed that the accident airplane's autopilot was functioning within its design tolerances; however, the autopilot's 150-second desensitization rate was too slow for the accident airplane's approach speed, resulting in divergent pitch deviations at a low altitude at a critical time during the approach.[32]

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[32] As a result of this investigation, on June 1, 2000, the Safety Board issued Safety Recommendations A-00-41 through -45 to the FAA. For more information, see the section titled, "Autopilot Pitch Sensitivity on Coupled Instrument Landing System Approaches."

The two main landing gear and parts of the airplane's lower aft section and left and right wings were strewn across the runway and along the debris path. Although ground visibility was poor, the south local tower air traffic controller did not instruct the flight crew to contact the ground controller after landing nor did he monitor the progress of the airplane after it was cleared to land, as required by FAA Order 7110.65M, "Air Traffic Control Handbook." For the first 5 minutes after the accident, the south local controller and his supervisor were unaware that the airplane had crashed. As a result, the south local controller cleared two air carrier flights to land on the debris-strewn runway after the accident. One of the airplanes landed uneventfully, and the other performed a touch-and-go, as directed by the south local controller after the driver of an airport ground vehicle observed debris on the runway and contacted the tower.

The aisle to the forward entry door was blocked by a ceiling stowage compartment door that had opened during impact; however, passengers and crewmembers evacuated the airplane without serious injury through the forward right, aft right, and aft left exit door and also through the four overwing exits. Additionally, two passenger seat belt attachments became unhooked at impact for undetermined reasons, causing minor injuries to one passenger.[33]

The investigation of the emergency response to the accident revealed that once the accident was reported to the airport Operations Command Center by a security officer, the dispatch of rescue personnel was timely; however, ATC failed to monitor a dedicated airport rescue frequency (119.25), as required by airport policy, which caused about a 1-minute delay for two emergency vehicles to obtain permission to access runway 14R.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the flight crew to maintain a proper pitch attitude for a successful landing or go-around. Contributing to the accident were the divergent pitch oscillations of the airplane, which occurred during the final approach and were the result of an improper autopilot desensitization rate.

[33] As a result of this investigation, on February 19, 1999, the Safety Board issued Safety Recommendations A-99-10 and -11 to the FAA. For more information, see the section titled, "Survival Aspects."