National Transportation Safety Board

Washington, D.C. 20594

Aircraft Accident Brief

Accident Number:	FTW03MA160
Operator and Flight Number:	Southwest Airlines Flight 2066
Aircraft and Registration:	Boeing 737-300, N343SW
Location:	Amarillo, Texas
Date:	May 24, 2003

HISTORY OF FLIGHT

On May 24, 2003, about 2136 central daylight time,[1] a Boeing 737-300 (737), N343SW, registered to and operated by Southwest Airlines Company (Southwest) as flight 2066, veered off the left side of runway 4 during landing at Amarillo International Airport (AMA), Amarillo, Texas. The flight crew steered the airplane back toward the runway, the nose landing gear collapsed, and the airplane came to a stop on the runway. The 63 passengers and 5 crewmembers were not injured, and the airplane sustained substantial damage. The scheduled domestic air carrier flight was operated under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 with an instrument flight rules (IFR) flight plan filed; visual meteorological conditions prevailed with thunderstorms in the vicinity of the airport. The flight originated from McCarran International Airport (LAS), Las Vegas, Nevada, about 1945.

The flight was the second and final leg during the second day of a 3-day trip sequence for the crew, which included the captain, the first officer, and the three flight attendants. The trip sequence began on May 23, 2003, about 1500 when the crew departed Chicago Midway International Airport (MDW), Chicago, Illinois, en route to Phoenix Sky Harbor International Airport (PHX), Phoenix, Arizona. The crew then flew to Portland International Airport (PDX), Portland, Oregon, arrived about 2210, and remained overnight in Portland. The next day, they departed PDX about 1730 for LAS. The flight to AMA was scheduled to depart about 1920 but was delayed because of late connecting passengers.

During post-accident interviews, the captain and the first officer stated that they checked the weather before departure and that they were aware that thunderstorms were expected in the AMA area. Their planned alternate destination was Love Field (DAL), Dallas, Texas.

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

According to cockpit voice recorder (CVR) information, during the airplane's descent, the captain contacted Southwest operations at AMA about 2125 for weather information. The captain stated, "looking up here on the radar it doesn't look very happy." The operations personnel replied, "we've got frequent, lot of lightning, ah light to moderate rain." About 2127, the Federal Aviation Administration (FAA) air traffic control (ATC) approach controller told the flight crew that winds were "quite variable" between 290º and 010º.[2] The controller advised the flight crew to expect a visual approach to runway 4. The captain responded, "okay copy and ah this storm is moving ah?" The controller replied, "south south east." The controller advised the flight crew to "descend at your discretion and maintain six thousand and ah looks like the…main cell is southwest of the airport ah just about to pass the final approach for runway four."

At 2128:00, the first officer, who was the pilot flying, began briefing the procedure for the instrument landing system (ILS) approach to runway 4. At 2128:45, the first officer briefed the procedure for the missed approach. He stated, "if we have to do the missed we go to forty one hundred feet [mean sea level (msl)] then climbing right turn. That kinda looks like that might be where the weather's heading, so…we might need something different than that." At 2128:58, the captain responded, "alright if it looks real [expletive deleted] on the way in then I'll ask…them what to anticipate on the way out."

At 2130:53, as the flight crew completed the Approach Descent checklist, the captain stated, "radar's aw, well," adding, 9 seconds later, "aw you've seen worse." The first officer responded, "hah. Absolutely." At 2131:22, the captain stated, "man you're gonna be a god out of this whole thing I can tell, a hero," which was followed by the sound of laughter.

At 2132:02, the captain suggested that the first officer descend the airplane to avoid lightning. Seven seconds later, the captain stated, "little bit of distance eh I'll take two thousand feet below it." At 2132:20, the captain stated, "he should be turning us here any minute but, no sense being a lightning rod." At 2132:39, the first officer responded, "oh [expletive deleted]…keep my hands off anything metal," which was followed by the sound of laughter.

The approach controller, who was also working the tower controller position, cleared the flight for the ILS runway 4 approach at 2132:45. At 2132:59, the captain told the controller, "we're just skirtin' … the very edge of the storm right now." The controller responded, "that's what I'm showin also." The captain replied, "rather be lucky." The sound of laughter was recorded at 2133:08. At 2133:10, the captain said,

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[2] The controller also advised the flight crew that automatic terminal information service (ATIS) Kilo was in effect. The flight crewmembers had advised the controller that they had ATIS information Juliet. The controller stated, "ceilings are still at five thousand five hundred…five thousand five hundred broken and nine thousand five hundred overcast." ATIS information Juliet included an advisory that stated, "notice to airmen: hazardous weather information available on HIWAS [hazardous in-flight weather advisory service] or from Fort Worth flight service."

“holy [expletive deleted], good luck.” At 2133:33, the controller stated that the winds were from “two four zero variable to two nine zero at five knots or less” and that “there is a thunderstorm light and light rain at the airport.” The captain replied, “alright, so we still got the field in sight … but visibility starting to deteriorate we’re just getting into rain now.” According to airport surveillance radar-8 data, the flight intercepted the runway 4 localizer about 8.8 miles from the runway threshold.

At 2134:13, the captain said to the first officer, “why don’t you fly this one [the approach and landing],” and the first officer acknowledged the captain’s statement. Two seconds later, the captain stated, “glideslope’s alive.”[3] At 2134:26, the captain stated, “gear down. Wow. This is really gonna be gusty.” Twenty seconds later, the controller stated the winds were “switching southwest now it’s two two zero at niner.” The flight crew continued the approach, lowered the flaps, and completed the Final Descent checklist. At 2135:35, the captain stated, “okay checklist complete I think it’s a good call,” followed by a sound similar to trim wheel movement. The captain stated, “holy [expletive deleted]” at 2135:40, “wow” 5 seconds later, and then “okay airport in sight.” At 2135:48, the captain asked the controller to “keep the lights up for southwest ah twenty sixty six.”[4] The controller replied, “winds right now one niner zero now at eight.”

At 2135:55, the first officer stated, “approaching minimums,” and the captain responded, “going outside.” At 2136:02, the first officer called for windshield wipers, and a sound similar to windshield wiper operation was recorded 2 seconds later. At 2136:05, the captain stated, “keep it comin'” and “landing” 4 seconds later. At 2136:11, the CVR recorded the sound of the autopilot disconnect warning tone, and, 3 seconds later, the captain stated, “do it…you can do it.” Seven seconds later, the captain stated, “ten feet, put her down.” At 2136:27, a sound similar to touchdown was recorded on the CVR.

According to the flight data recorder (FDR), thrust reversers[5] were deployed at 2136:30. At 2136:31, the controller began a 4-second transmission, stating that the wind direction had changed (190° to 230°) and that the wind velocity was gusting to 18 knots. At 2136:33, the captain stated, “I’m on with you.” The sound of rumbling began 1 second later, followed by an expletive by the captain. At the same time, the first officer stated, “you got it.” FDR data indicated that maximum reverse thrust was reached at this time, the right rudder pedal position was 12.9° airplane nose right, and the control wheel input was 29.2° right wing down. A series of sharp crashing sounds was recorded by the CVR at 2136:35. Two seconds later, the left rudder pedal position was 13.1° airplane nose left, and, 1 second later, the control wheel input was 29.2° left wing down. Also at 2136:37, the CVR recorded an expletive by the captain, followed by the sound of rumbling. The CVR recording ended at 2136:43. The airplane came to a stop on runway 4 about 4,272 feet beyond the threshold.

[3] The glideslope provides vertical guidance on the ILS approach.

[4] The tower controller stated, during a postaccident interview, that the approach lights were turned up to the highest setting and that the runway lights were turned to the second-highest setting.

[5] Thrust reversers redirect engine exhaust to help slow the airplane.

Flight Crew Statements

The captain stated, during a postaccident interview, that the en route flight was uneventful and smooth. He stated the airborne weather radar was set in the "WX" mode and had depicted no significant weather when set at the 320-mile range; he stated the radar had depicted a "small" weather return near AMA when set at the 160-mile range. The captain stated he listened to ATIS information Juliet (see the Meteorological Information section for details about ATIS and other weather information). The captain stated that, when the airplane was at 23,000 feet during descent, he heard the controller say that a thunderstorm was at the airport. The captain said he could see the Amarillo city lights out the window, the weather did not appear to be over the airport, and he did not recall seeing a thunderstorm at the airport.

He stated he progressed down the ranges on the weather radar, and the last setting was the 20-mile range with the antenna tilted up about 2° to 3°. He stated that, during the approach, the weather buildup was about 10 miles away with a thunderstorm about 5 to 8 miles past the airport. He stated, "the information I was getting [from the radar] agreed with what I was seeing [out the window]," He stated, "the weather radar was painting green with some yellow," and he did not see any red returns depicted over the airport. He stated, "our flight path was taking us away from the weather." He stated the rain was light as the airplane neared the runway, and he never lost sight of the field. The flight encountered moderate to heavy rain as it approached the ILS minimum descent altitude, and visibility decreased in the heavy rain before landing.

The captain stated the touchdown was "firm," and the airplane immediately began to drift to the left, even though the nose was pointed straight down the runway. He stated he had no sensation of friction. He stated he took control of the airplane from the first officer after it began sliding, and he applied nosewheel steering but was cautious because of the airplane's speed. He stated he felt the nosewheel "grab" one or two times. He stated he did not apply brakes, and he could not recall making rudder or aileron control inputs. He stated there was a loud "pop" when the airplane returned to the runway, and the airplane then slid to a stop. The captain stated he had last flown to AMA in February 2000, and he had "maybe been to AMA three times before that."

During a postaccident interview, the first officer stated the airport was in sight during the approach, and clouds were about 6 to 8 miles to the right of the airplane. He stated he did not continuously monitor the weather radar during the approach because he was looking outside the airplane. He said he saw one thunderstorm cell with lightning about 6 miles to the right of the approach course, and they encountered light rain about 5 miles from the ILS runway 4 final approach fix. They encountered moderate rain as they descended to 300 feet above ground level (agl). He stated the landing was "firm," and the airplane touched down about 1,000 feet down the runway in the center of the runway, and the airplane began sliding to the left after touchdown. He stated the airplane did not respond to rudder inputs, but it did respond to control inputs when it was off the runway. The first officer stated the accident flight was his first flight to AMA.

DAMAGE TO AIRPLANE

The airplane received substantial damage during the accident.

OTHER DAMAGE

The airport's runway lights and fixtures and runway edge safety area were damaged as a result of the accident.

PERSONNEL INFORMATION

The Captain

The captain, age 50, held an airline transport pilot (ATP) certificate issued on October 20, 1992, with a rating for airplane multiengine land and type ratings for 737 and L-300 airplanes. He also held commercial privileges for airplane single-engine land and single-engine sea. His most recent FAA first-class airman medical certificate was issued on May 5, 2003, with the following limitation: "wear lenses for distant – possess glasses for near vision."

The captain was hired by Southwest on March 3, 1994. According to the captain, he had accumulated about 9,400 hours total flight time, of which about 5,400 hours were in the 737. He stated he had logged about 600 hours pilot-in-command (PIC) time in the 737. He was upgraded to captain in July 2000. In the 90, 30, and 7 days before the accident, he had flown about 156, 48, and 4.8 hours, respectively.

The captain stated he graduated from the U.S. Air Force Academy in 1976 and subsequently flew C-141 airplanes for 6 years as first officer and aircraft commander, logging 3,500 total hours and 1,500 hours as PIC. He also logged about 500 hours in F-16 airplanes.

The captain received a recurrent proficiency check on January 22, 2003, and a recurrent line check on June 7, 2002. He stated he received weather radar training in the classroom during his upgrade operating experience training and during recurrent training.

A review of FAA airman records revealed no previous accidents, incidents, or enforcement action against the captain. The National Driver Register showed no history of driver's license revocation or suspension.

According to the captain, on the night before the first day of the trip sequence, he commuted from Denver International Airport, Denver, Colorado, to MDW on a commerical flight that departed about 1845 mountain daylight time and arrived about 2300. He went to bed about 0000. He awoke about 0830 and went to Southwest operations at MDW about 1100. He checked company publications and the "read before fly" book and ate lunch.

After he arrived in PDX, the captain met with the rest of the crew at the hotel and drank one beer. He said he went to bed about 2330 Pacific daylight time. He awoke the next morning between 0800 and 0830 and ate breakfast. He did some personal errands in the morning and then went shopping with the first officer. He checked in at PDX about 1430 for the flight to LAS.

The First Officer

The first officer, age 44, held an ATP certificate issued on September 27, 1991, and was type rated for 737 airplanes on November 10, 1998. He also held a type rating for DHC-8 airplanes and commercial privileges for airplane single-engine land. He held an FAA first-class airman medical certificate issued on May 15, 2003, with no limitations.

The first officer worked as a flight instructor from 1990 to 1992 and then was hired by Allegheny Airlines, a USAir contract commuter airline. He worked as a first officer and then as a captain on DHC-8 airplanes before joining Southwest on August 30, 2001.

The first officer logged a total of 10,000 flying hours, of which about 4,300 hours were as PIC and about 1,200 hours of which were in 737 airplanes. In the 90, 30, and 7 days before the accident, he had flown about 253, 94, and 4.8 hours, respectively.

He received his initial operating experience at Southwest on October 18, 2001, during which he received training on the operation of the airborne weather radar system. He also received classroom training on en route weather radar as a new hire and during recurrent training.

A review of FAA airman records revealed no accidents, incidents, or enforcement action against the first officer. The National Driver Register showed no history of driver's license revocation or suspension.

According to the first officer, on the night before the first day of the trip sequence, he went to bed about 2200 eastern daylight time and awoke the next day about 0630. He departed Cleveland-Hopkins International Airport, Cleveland, Ohio, about 0930 eastern daylight time on a flight to MDW and arrived about 0930. Afterward, he took a nap and checked in at MDW about 1300 for his flight to PHX. After finishing the leg to PDX, he met the rest of the crew and ate. He went to bed about 0000.

The first officer awoke about 0830, engaged in normal activities in the morning, and ate lunch. He checked in about 1630 for the flight to LAS.

The Flight Attendants

The three flight attendants were qualified on 737 airplanes. They had completed the company's initial training, which included instruction in emergency procedures and evacuation drills, and had completed their most recent recurrent company emergency procedures training in 2002 or 2003. The "A" flight attendant was assigned the forward outboard jumpseat position, the "B" flight attendant was assigned the aft jumpseat position, and the "C" flight attendant was assigned the forward inboard jumpseat position.

The Air Traffic Controller

The AMA tower and approach controller was a radar approach controller in the U.S. Air Force from 1969 to 1973. He was hired as an air traffic controller by the FAA in 1975 but left the FAA in 1981 and then returned in 1997. His control tower operator certificate was issued on September 6, 1998. He began working at the AMA control tower in April 2002 and was fully certified in October 2002. His medical certificate was current at the time of the accident.

At the time of the accident, the controller was alone in the tower cab working all positions, which he stated was standard practice for a Saturday night. He stated he monitored the flight's approach on the tower radar display, but he did not see the airplane on the approach, and he did not see it cross the runway threshold. He stated he tried to visually locate the airplane on the runway or taxiway using binoculars, but he was not successful because of the heavy rain.

AIRPLANE INFORMATION

The airplane, serial number (S/N) 24151, was equipped with two General Electric CFM-56 engines. At the time of the accident, the airplane had accumulated 48,001 flight hours and 45,130 cycles.[6] According to Southwest records, the No. 1 engine was installed on June 12, 2001, and had accumulated 22,555 hours and 19,177 cycles.[7] The No. 2 engine was installed on June 14, 2001, and had accumulated 32,202 hours and 29,216 cycles. No open maintenance discrepancies were noted in the airplane's logbook.

METEOROLOGICAL INFORMATION

Automated Surface Observing System

Automated Surface Observing System (ASOS)[8] weather observations at AMA were maintained by the National Weather Service (NWS) and augmented by ATC

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[6] An airplane cycle is one complete takeoff and landing sequence.

[7] An engine cycle is one complete startup and shutdown sequence.

[8] The ASOS sensor and the anemometer supplying wind data to the control tower were located on the north side of runway 4, about 6,500 feet from the threshold.

personnel in the control tower who were certified weather observers. The ASOS recorded continuous information on wind speed and direction, cloud cover, temperature, precipitation, and visibility; it also transmitted special weather observations for conditions such as wind shifts and visibility and ceiling changes.

The most recent official airport observation, an augmented ASOS special weather observation at 2137,[9] was available about 1 minute after the accident. The observation stated the following:

> 0237Z Special Observation. Wind from 200º at 11 knots with gusts to 18 knots, visibility 2 miles, thunderstorm, heavy rain, few clouds at 600 feet, ceilings 1,700 feet broken and 5,500 feet overcast, temperature 18º Celsius (C), dew point 15º C, altimeter setting 30.04 inches of mercury (Hg), wind shift at 0207Z, thunderstorm began 0157Z, rain began 0158Z, pressure rising rapidly, 0.22 inch of precipitation between 0153Z and 0237Z, 0.19 inch of precipitation between 0227Z and 0237Z.

ASOS observations, which were updated at 5-minute intervals during the flight's approach, included the following:

> 0215:31Z. Wind from 060º at 16 knots with gusts to 22 knots, visibility 10 miles, thunderstorm, light rain, few clouds at 5,500 feet, ceilings 7,500 feet broken and 9,500 feet overcast, altimeter setting 29.97 inches of Hg, 0.01 inch of precipitation recorded.

> 0220:31Z. Wind from 070º at 15 knots, visibility 10 miles, thunderstorm, light rain, scattered clouds at 5,500 feet, ceilings 7,000 feet broken and 10,000 feet overcast, altimeter setting 29.98 inches of Hg, 0.02 inch of precipitation recorded.

> 0225:31Z. Wind from 350º at 10 knots; wind direction variable between 310º and 020º; visibility 10 miles; thunderstorm; light rain; ceilings 5,500 feet broken, 7,000 feet broken, and 9,500 feet overcast; altimeter setting 30.01 inches of Hg; 0.02 inch of precipitation recorded.

> 0230:31Z. Wind from 310º at 8 knots, visibility 9 miles, thunderstorm, light rain, few clouds at 1,700 feet, ceilings 5,500 feet broken and 9,500 feet overcast, altimeter setting 30.03 inches of Hg, 0.03 inch of precipitation recorded.

[9] Weather observations are transmitted in coordinated universal time (UTC). The "Z" designation that follows the time in the weather observation stands for Zulu, which indicates UTC time. Central daylight time is 5 hours behind UTC time.

> 0235:31Z. Winds variable at 6 knots, visibility 3 miles, thunderstorm, heavy rain, scattered clouds at 1,700 feet, ceilings 4,800 feet broken and 7,000 feet overcast, altimeter setting 30.04 inches of Hg, 0.10 inch of precipitation recorded.

> 0240:31Z. Wind from 110º at 7 knots with gusts to 18 knots, wind direction variable between 070º and 150º, visibility 1 mile, thunderstorm, heavy rain, mist, few clouds at 400 feet, ceilings 1,700 feet broken and 5,500 feet overcast, altimeter setting 30.05 inches of Hg, 0.46 inch of precipitation recorded.

On the basis of the ASOS observations, the Safety Board estimated that 0.12 inch of precipitation fell at a rate of 3.6 inches per hour between 2135 and 2137 and that 0.24 inch of precipitation fell at a rate of 4.8 inches per hour between 2137 and 2140.

Automatic Terminal Information Service Information

ATIS information is based on ASOS observations. ATIS information Juliet, transmitted at 0207Z, was current when the flight was en route, and ATIS information Kilo, transmitted at 0223Z, was current at the time of the approach and landing. The ATIS information stated, in part, the following:

> Amarillo International Airport Information Juliet, 0201 observation. Wind 120 at 12. Few clouds at 9,000; 11,000 overcast. Visibility 10 miles. Thunderstorm. Temperature 24, dew point 14. Altimeter 2998. Notice to airmen: hazardous weather information available on HIWAS [hazardous in-flight weather advisory service] or from Fort Worth flight service.

> Amarillo International Airport Information Kilo, 0221 special observation. Wind 060 at 17. Weather: 5,500 broken; 7,000 broken; 9,500 overcast. Visibility 10. Thunderstorm, light rain showers. Temperature 18, dew point 15. Altimeter 2999. Visual approach in use for landing and departing runway 4 and 13. Notice to airmen: for hazardous weather information contact Fort Worth radio or HIWAS.

Terminal Aerodrome Forecasts

The following NWS terminal aerodrome forecasts (TAF) were in effect for AMA at the time of the accident:

> From May 25, 2003, at 0000Z: Wind from 100º at 12 knots, visibility greater than 6 miles, few clouds at 6,000 feet, ceiling 20,000 feet broken.

> From May 25, 2003, at 0200Z: Wind from 080º at 10 knots, visibility greater than 6 miles, scattered clouds at 4,000 feet, ceiling 10,000 feet overcast.
>
> Temporary conditions (TEMPO) May 25, 2003, from 0200Z to 0600Z: Visibility 3 miles, thunderstorm, moderate rain, ceiling 2,500 feet overcast with cumulonimbus clouds.

Southwest Weather Information

The preflight weather package provided to the flight crew contained the May 25, 2003, 0000Z TAF for AMA. The package also contained surface weather observations for AMA and a convective SIGMET (significant meteorological information) that was issued on May 24, 2003, at 2355Z. A Convective SIGMET implies severe or greater turbulence and low-level windshear activity.

Convective SIGMET 8C, which was issued at 0155Z while the flight was en route, was in effect for the time of the accident for an area that included AMA.[10] Convective SIGMET 8C was not forwarded to the flight crew by Southwest dispatch, as required by 14 CFR 121.601. Convective SIGMET 8C indicated an area of severe thunderstorms moving from 270º at 30 knots with tops to flight level 440 (44,000 feet pressure altitude). Convective SIGMET 8C also noted the possibility of 1-inch hail and wind gusts to 50 knots.

The flight's release information package contained several SIGMETs, including 81C, which was issued at 2355Z and indicated that an area of severe thunderstorms was located about 50 miles west of AMA and was moving from 270° at 30 knots.

Severe Thunderstorm Watch

Severe Thunderstorm Watch No. 429 was in effect for an area that extended just to the south of AMA. The watch indicated hail up to 2 inches and wind gusts to 60 knots. The watch noted maximum cloud tops to 50,000 feet. The watch was issued by the Storm Prediction Center in Norman, Oklahoma, on May 25, 2003, at 0140Z and was valid until 0700Z.[11]

Weather Radar Products

Data from the AMA WSR-88D Doppler weather radar were obtained from the National Climatic Data Center in Asheville, North Carolina. The system provides a three-

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[10] Convective SIGMET 8C was issued by the Aviation Weather Center in Kansas City, Missouri, at 0155Z and was valid until May 25, 2003, at 0355Z.

[11] The Safety Board was not able to determine whether severe thunderstorm watch 429 was provided to the flight crew en route by Southwest dispatch.

dimensional volume scan of the atmosphere at varying degrees of elevation. The volume scan process takes 5 minutes and progresses in 360º sweeps at increasing elevations.[12] Radar analysis software was used to review the WSR-88D data and generate cross-section reflectivity images and base reflectivity images.

For the 0232:40Z scan, the cross-section reflectivity image indicates that the weather echo intensities along the approach to runway 4 reached 54 decibels (dBz), or level 5 (intense) activity (see figure 1).[13]

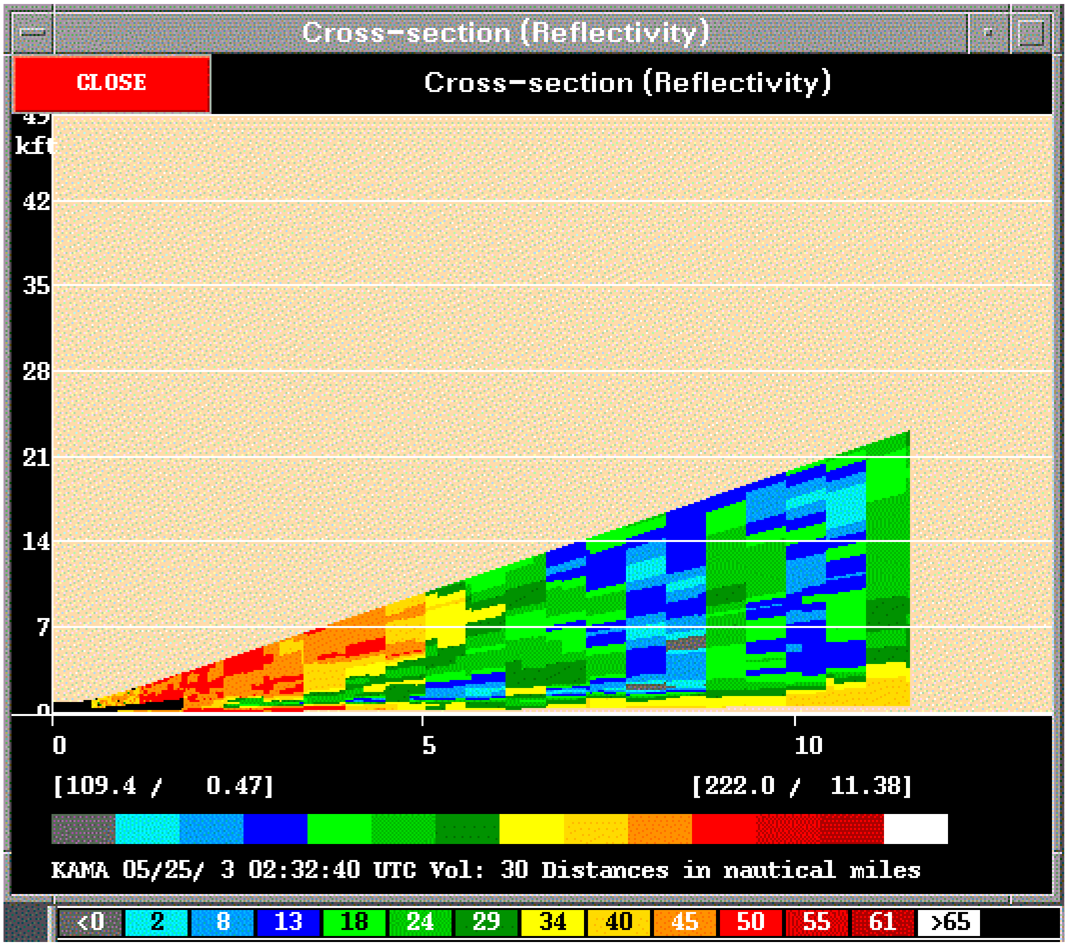

Figure 1. Weather Echo Intensity Cross-Section for 0232:40Z.

Note: The scan includes the flight's approach ground track from about 13 nautical miles (nm) from the runway 4 threshold to the runway threshold. Heights are in feet above the AMA weather radar antenna elevation at 3,668 feet msl. Distances are in nm from the runway 4 threshold. The scale at the bottom of the chart depicts the intensity range in dBz.

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[12] The WSR-88D weather radar information was not directly available to the flight crew.

[13] The NWS categorizes reflectivity according to a six-level intensity scale: level 6 is the highest, measuring 55 dBz or greater. The other levels include 1, very light; 2, light to moderate; 3, strong; 4, very strong; and 5, intense.

For the 0232:40Z scan, the base reflectivity image indicates that very strong to intense weather radar echoes were detected along the approach to runway 4 (see figure 2).

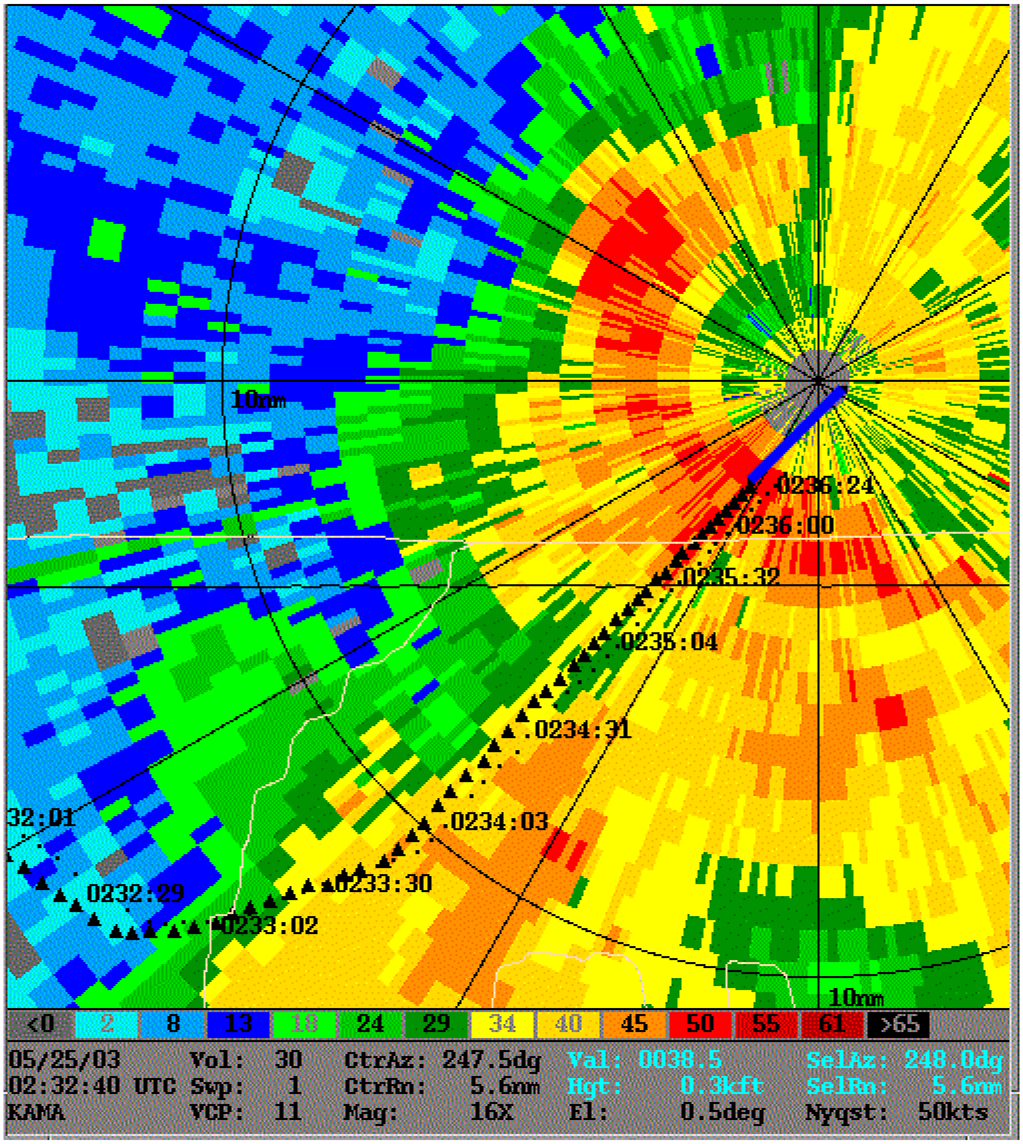

Figure 2. Base Reflectivity Image for 0232:40Z (0.5º elevation angle).

Note: The ground track of the flight is identified by black triangles. Runway 4 is shown in blue. The scale at the bottom of the chart depicts the intensity range in dBz. The weather radar beam center near the runway 4 threshold is about 200 feet above the runway elevation.

For the 0237:39Z scan, the cross-section reflectivity image indicates that very strong weather echoes were detected in the approach area of runway 4 (see figure 3).

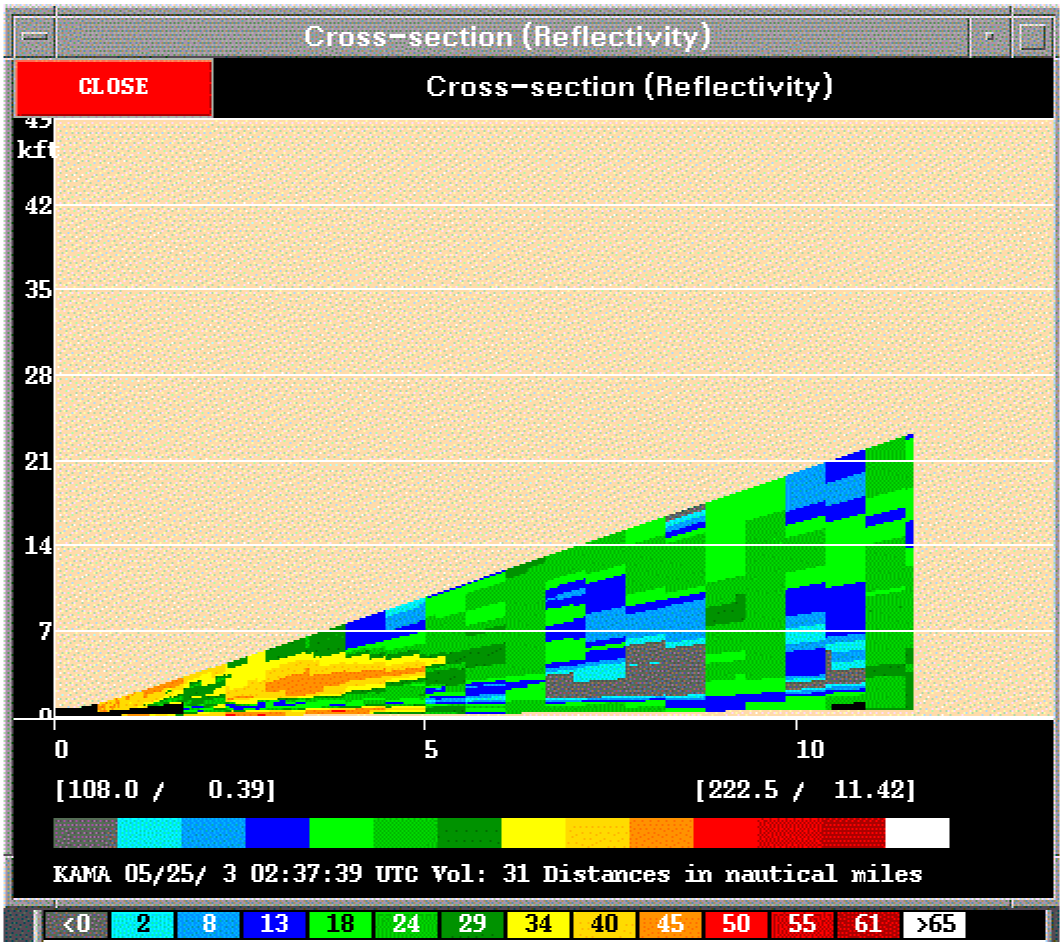

Figure 3. Weather Echo Intensity Cross-Section for 0237:39Z.
Note: The scan is along the flight's approach ground track from about 13 nm from the runway 4 threshold to the runway threshold. Heights are in feet above the AMA weather radar antenna elevation at 3,668 feet msl. Distances are in nm from the runway 4 threshold. The scale at the bottom of the chart depicts the intensity range in dBz.

For the 0237:39Z scan, the base reflectivity image indicates that very strong weather radar echoes were detected in the approach area to runway 4. Strong or greater weather echoes were detected from about 3 nm southwest of the runway 4 threshold to the runway threshold (see figure 4).

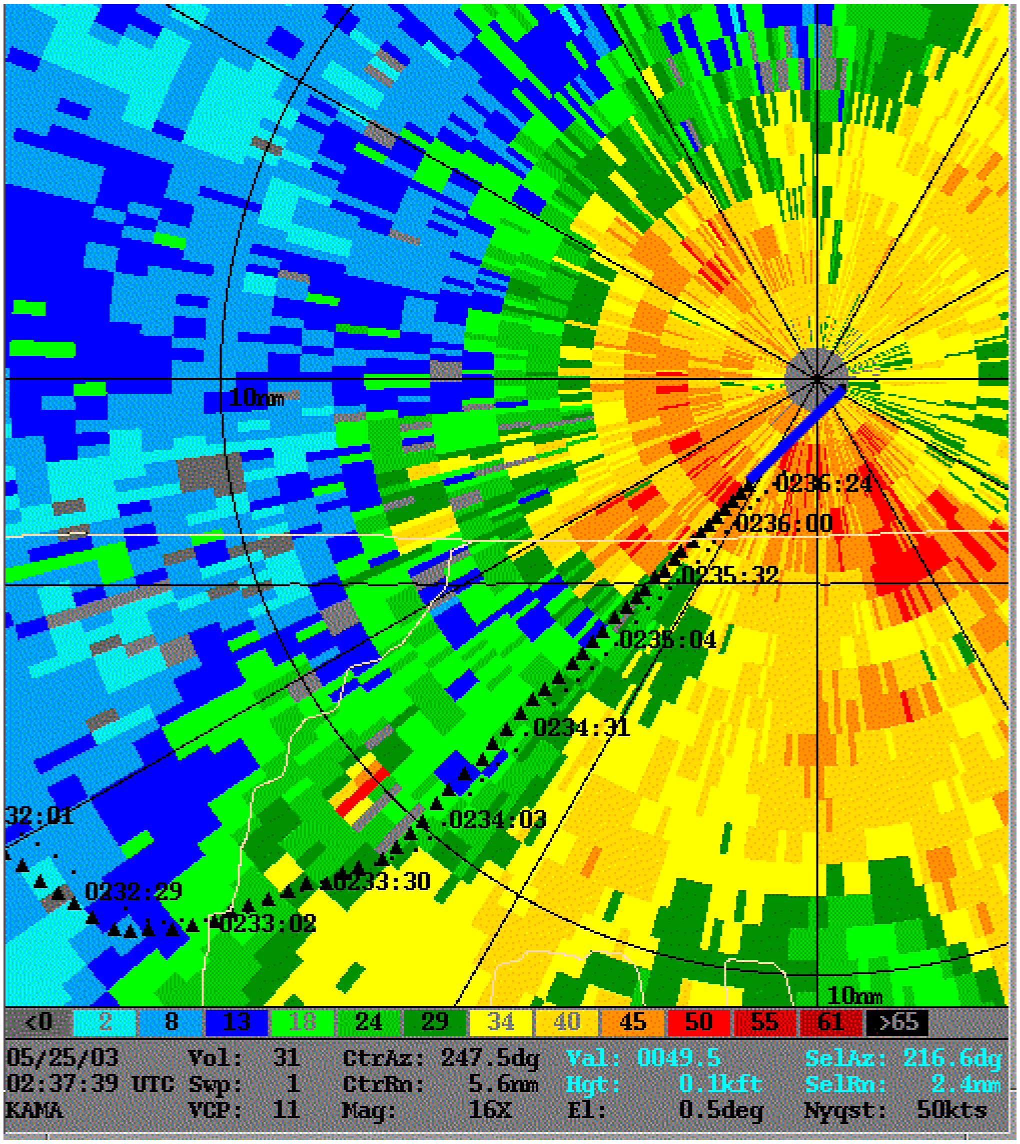

Figure 4. Base Reflectivity Image for 0237:39Z (0.5º elevation angle).

Note: The ground track of the flight is identified by black triangles. Runway 4 is shown in blue. The weather radar beam center near the runway 4 threshold is about 200 feet above the runway elevation. The scale at the bottom of the chart depicts the intensity range in dBz.

Lightning Data

According to the National Lightning Detection Network (NLDN),[14] 505 cloud-to-ground strikes were recorded within a 15-mile radius of the runway 4 threshold between 0225Z and 0240Z. A cloud-to-ground lightning strike was recorded near the runway 4 threshold at 0233:23Z. About seven cloud-to-ground lightning strikes were recorded near or along the airplane's flightpath from 0233Z to 0237Z (see figure 5).

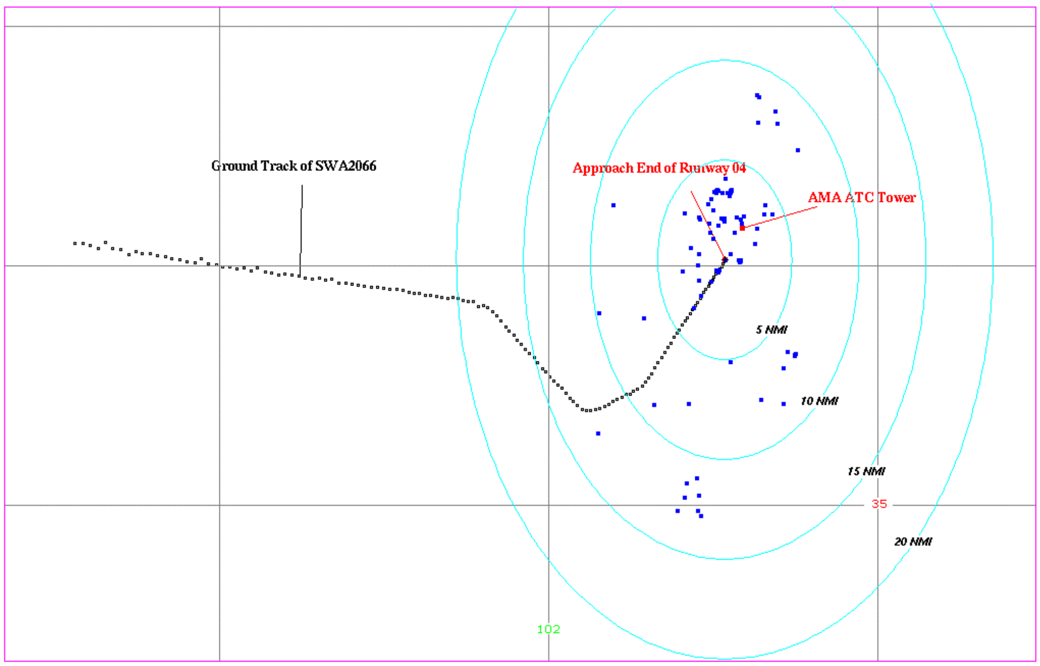

Figure 5. Cloud-to-Ground Lightning Strikes From 0233Z to 0237Z.
Note: Blue squares depict lightning strikes, and irregular blue points represent multiple strikes in the same area. The airplane's ground track is shown in black. About 99 lightning strikes were recorded during this time period. The range rings indicate distance from the runway 4 threshold in 5-nm increments.

AIRPORT INFORMATION

AMA is located about 6 miles east of metropolitan Amarillo at an elevation of 3,607 feet msl. AMA has an FAA-approved airport emergency plan and is certified by the FAA as an aircraft rescue and firefighting (ARFF) index C facility under 14 CFR Part 139.[15] The ARFF facility, Station 10, is operated by the Amarillo Fire Department (AFD)

[14] Lightning data plots were generated using NLDN information and displayed by the Man Computer Interactive Data Access System, which is a meteorological analysis and data management computer system administered by the Space Science and Engineering Center at the University of Wisconsin.

[15] According to 14 CFR Part 139.315 and Part 139.317, an index C facility is required to have ARFF vehicles with a total capacity to carry 500 pounds of sodium-based dry chemical, halon, or clean agent and 3,000 gallons of water.

and is staffed 24 hours a day by six firefighters. The station has two primary crash trucks, one command vehicle, and one reserve crash truck. In addition to the ARFF vehicles, Station 10 houses Engine No. 10, a truck primarily assigned to respond to structural emergencies on and off the airport.

The tower is located near the northeast end of runway 4, about 2 miles from the touchdown zone. The ARFF station is located at the northeast end of the south ramp, about 1.5 miles from the accident site.

AMA has two partially grooved, concrete runways, 4/22 and 13/31. Both runways are accessible by full-length parallel taxiways. All taxiways are equipped with medium-intensity taxiway edge lights.

Runway 4/22, which is 13,502 feet long and 300 feet wide,[16] was equipped with high-intensity runway edge lights and a medium-intensity approach lighting system with runway alignment indicator lights. The runway was also equipped with a four-light, 3° glidepath visual precision approach path indicator. The runway was not equipped with runway centerline lights or touchdown zone lights. According to the tower controller, when the flight was on approach, the runway 4 approach lights were at the highest setting, and the runway lights were at the second-highest setting. Runway 4 was configured for precision and nonprecision approaches, which included ILS, global positioning system, and nondirectional beacon approaches.

In 1986, 130-foot continuous grooves were cut along the entire length of the runway, extending 65 feet from each side of the runway centerline. Rubber removal was accomplished in April 2003 on the first 4,500 feet of runway 4 and the first 5,400 feet of runway 22.

FLIGHT RECORDERS

Cockpit Voice Recorder

The airplane was equipped with an Allied Signal model 6022 solid-state CVR, S/N 2605. The exterior of the CVR showed no evidence of structural damage. The CVR was sent to the Safety Board’s audio laboratory in Washington, D.C., for readout and evaluation.

The 30-minute recording consisted of four channels of good to fair quality[17] audio information. The four channels contained the jumpseat auxiliary microphone, the

[16] Most transport-category airport runways are about 150 feet wide.

[17] The Safety Board ranks the quality of CVR recordings in five categories: excellent, good, fair, poor, and unusable. In a good quality recording, most of the crew conversations are accurately and easily understood. The transcript developed from the recording might indicate several words or phrases that were not intelligible; such losses are attributed to minor technical deficiencies, momentary dropouts in the recording system, or simultaneous cockpit/radio transmissions that obscure one another. In a fair quality

captain's audio panel, the first officer's audio panel, and the cockpit area microphone. A transcript was prepared for the period from 2124:56 to 2136:43.[18]

Flight Data Recorder

The airplane was equipped with a L-3 Fairchild solid-state FDR model FA-2100, S/N 1070. The FDR was recovered in good condition and sent to the Safety Board's FDR laboratory in Washington, D.C., for readout and examination.

A review of the recorded data, which were converted based on information obtained from Southwest, indicated that the sample rate of several parameters did not meet the requirements of 14 CFR 121.344(c). The following parameters were recorded only once per second: control column position, control wheel position, rudder pedal position, and rudder position. Left aileron and left elevator positions were recorded only once every other second. According to 14 CFR Part 121.344(c), effective August 18, 2001, these parameters must be recorded at a sampling interval of 0.5 second as stated in Appendix M to 14 CFR Part 121, "Airplane Flight Recorder Specifications."

Safety Board investigators notified Southwest of the higher sampling intervals for the parameters that were not in compliance with 14 CFR Part 121.344(c). After an internal review, the airline determined the dataframe[19] used on the flight data acquisition units on all of its Boeing 737-300 and -500 series airplanes predated the parameter upgrades. Even though the dataframe included all of the required parameters, the sampling intervals used did not meet requirements for the parameters of control column position, control wheel position, rudder pedal position, rudder position, left aileron position, and left elevator position.

Southwest subsequently began upgrading the dataframes on the flight data acquisition units on all its Boeing 737-300 and -500 series airplanes to ensure that the information being recorded on the FDRs was in compliance with 14 CFR Part 121.344(c). Southwest completed the upgrades in October 2003.

WRECKAGE AND IMPACT INFORMATION

Marks found on runway 4 and in the grass to the left of the runway indicated that the airplane came to a stop about 4,272 feet from the threshold.[20] White tracks that were

recording, most of the crew conversations are intelligible. The transcript developed might indicate passages where conversations were not intelligible or were fragmented; such losses are attributed to cockpit noise or minor electrical or mechanical failures of the CVR system that distort or obscure the audio information.

[18] The end of the recording is consistent with the loss of electrical power that occurred after the nose landing gear collapsed into the electrical bay.

[19] The dataframe defines the parameter information sent to the FDR.

[20] Runway and off-runway observations were conducted by AMA personnel, Southwest representatives, and representatives of the Southwest Airlines Pilots' Association. Each group submitted runway diagrams and witness mark information, which were reviewed and collated by the Safety Board.

consistent with tire marks[21] were found about 1,250 feet from the threshold and 60 feet from the runway's left edge. Ground scarring indicated that the left main landing gear's outboard tire went off the left edge of the runway 2,575 feet from the threshold, followed by the left gear inboard tire at 2,700 feet. The nosewheel went off the runway at 3,000 feet, and nosewheel ground tracks ended at 3,475 feet, which was consistent with the collapse of the nose landing gear. Ground scarring also indicated that the right main landing gear was off the runway 3,175 feet from the threshold. Ground and runway markings indicated that the right main landing gear was back on the runway 3,750 feet from the threshold, followed by the left main landing gear at 3,837 feet.

The airplane's nose landing gear collapsed rearward and damaged the avionics bay in the forward fuselage. Both engines sustained foreign object damage.

SURVIVAL ASPECTS

Aircraft Rescue and Firefighting Response

According to the ARFF incident report, the crash alarm sounded at 2140:28, and ARFF units arrived at the accident location at 2142:44.[22] According to the Amarillo Fire Department incident report, the ARFF captain, who was the incident commander, stated that the tower controller said the tower had lost contact with an inbound Southwest 737. The incident commander also stated, "the tower said that it [the airplane's data block] had gone off the radar screen." The incident commander stated that, after declaring an alert 2A,[23] the ARFF units began a search. He stated the ARFF units drove through heavy rain and high winds down taxiway Papa to the approach end of runway 4. In his postaccident narrative, the incident commander stated the following:

> At the approach end of runway 4 Engine 10 and Red 3 checked for a short landing, and Red 1 and Red 2 proceeded down runway 4.[24] Engine 10 and Red 3 concluded the aircraft did not land short and proceeded down runway 4. Red 2 spotted the aircraft at the intersection of runway 4 and taxiway Alpha. The aircraft had a collapsed nose gear and debris all over it

[21] The tire marks were more whitish in color than the surrounding off-white concrete surface.

[22] According to 14 CFR Part 139.9, at least one ARFF vehicle must be capable of a 3-minute response time to the "midpoint of the furthest runway serving air carrier aircraft from its assigned post, or reach any other specified point of comparable distance on the movement area which is available to air carriers" and then must begin applying agent. In addition, 14 CFR Part 139.9 requires that all other ARFF vehicles reach the same specified point and begin applying agent within 4 minutes.

[23] An alert 2A indicates that a large airplane with more than eight passengers is approaching with on-board conditions including an engine fire, faulty landing gear, or low hydraulic pressure.

[24] Engine 10, a 1995 Spartan, carried 500 gallons of water and was equipped with hand lines and a 24-foot extension ladder. Red 1, a 1990 Chevrolet Suburban, was the command vehicle. Red 2, a 1993 Walter BGD-1500 quick-response vehicle, was equipped with a roof turret, a bumper turret, and a hand line. Red 3, a 2001 KMEB-1500, was equipped with a roof turret, a bumper turret, and FLIR. Red 4, a 1990 E-One Titan III backup truck, was equipped with a roof turret and a bumper turret. Red 2, 3, and 4 carried 1,500 gallons of water, about 180 to 200 gallons of aqueous film-forming foam, and about 450 to 500 pounds of dry chemical.

> from landing to the side of the runway and steering back on to the runway. An Alert 3A[25] was declared, and we made contact with the crew and determined that there were no injuries and made provisions to evacuate the aircraft and provide transport to the terminal.

The driver of Red 3 stated he proceeded "really slow" because of the poor visibility. He stated he could not see the other trucks. Red 3 was equipped with a Raytheon Nightsight Series 200 forward-looking infrared device (FLIR). The Red 3 driver stated he did not use the FLIR because it was not in a "good location" to be viewed while driving in poor visibility. The FLIR screen was mounted on the passenger side of the cab. The Red 3 driver stated the FLIR unit is used to locate "hot spots" inside an airplane caused by fire.[26]

Flight Crew and Flight Attendant Responses

The captain stated he and the first officer performed the emergency evacuation checklist after the airplane came to a stop. The No. 1 engine had a fire indication, and the captain pulled the fire handle to release the extinguisher bottle. He stated he attempted to contact the flight attendants on the public address system but was not successful; the electrical system was damaged. He then opened the cockpit door and talked to the flight attendants and the passengers. He stated the passengers remained in their seats. He stated that attempts to contact the control tower by radio were not successful. The captain stated he told the flight attendants not to initiate an emergency evacuation because there were no observations of smoke or flames and no indication of serious damage. He told the flight attendants to disarm the doors.

The "A" flight attendant stated the emergency lights came on after the airplane stopped, and she then got up and looked out the window. She stated she did not initiate an evacuation, because she did not see smoke or fire. The public address system did not work, so she got the megaphone from the left forward overhead bin and told passengers to remain seated. She stated the captain opened the cockpit door about the same time she was reassuring the passengers. She stated the captain confirmed her decision not to evacuate, stating that there would be no evacuation because there was no smoke or fire, and he asked her to keep everyone seated. She stated the flight attendants went through the cabin to reassure the passengers and to determine if anyone was injured.

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[25] Alert 3A indicates that a large airplane with more than eight passengers has been involved in an accident on the airport.

[26] The Safety Board asked Raytheon if a truck-mounted Nightsight 200 FLIR unit was capable of detecting an airplane on the ground from 8,000 to 12,000 feet away during snow, rain, or fog. The company stated it had not conducted specific tests to determine the device's capabilities in adverse weather conditions, but an independent study of thermal imaging devices similar to the Nightsight model concluded that thermal imaging cameras would suffer some loss of performance when operated in bad weather conditions. According to a Raytheon engineer, targets drenched by water in rainy weather would have cooler, more uniform surface temperatures, making them more difficult to detect. The effectiveness of imaging through atmospheric conditions such as rain, snow, or drizzle is also determined by the thickness of the precipitation and by how much heat the object was generating.

The “B” flight attendant stated she did not have authority to initiate an evacuation unless she saw smoke or fire, and she was waiting to hear instructions from the cockpit. She waited for about 1 minute and then got up to look out the windows for smoke or fire. She stated the “A” flight attendant was making an announcement, but she could not hear it. She stated she moved forward and determined that the megaphone was not working properly; it was fading in and out and could barely be heard midcabin. She stated she returned to the aft cabin, got the aft megaphone, and gave it to the “A” flight attendant about mid-cabin. She stated the “A” flight attendant then repeated the “no smoke, no fire” announcement again to the passengers.

The “C” flight attendant stated that, after the airplane came to a stop, the flight attendants remained seated and waited for the flight crew to give them instructions. She stated it “seemed like forever” but estimated it was about 30 seconds before the cockpit door opened. She stated the captain asked the flight attendants if they were okay and then said there was no smoke and no fire. She stated the captain asked her to open the forward entry door, so he could assess the situation outside the airplane. She stated, “it was raining so hard, a thunderstorm, that as soon as I opened the door, it felt like a bucket of water was poured on me. I was sopping wet.” She asked the captain if she should deploy the slide and he replied, “no, no slide evacuation necessary.”

ARFF personnel statements indicated passenger deplaning began about 30 minutes after the airplane stopped on the runway. According to flight attendant statements, the deplaning was well organized and accomplished without incident.

TESTS AND OTHER RESEARCH

Airplane Performance

FDR data, CVR data, and ground scar information were examined to determine the airplane’s flightpath and ground track before touchdown and the airplane’s ground roll after touchdown. The Safety Board conducted an FDR data flightpath integration study to calculate the airplane’s flightpath and ground track. In addition, the Aircraft Performance Group completed a kinematics study of the airplane’s motion during the approach and landing. The study used FDR data and kinematic extraction techniques to derive wind speeds, wind directions, and the ground track for the accident airplane. The ground tracks calculated by both methods were consistent with the markings on the runway (see figure 6 for integration results).

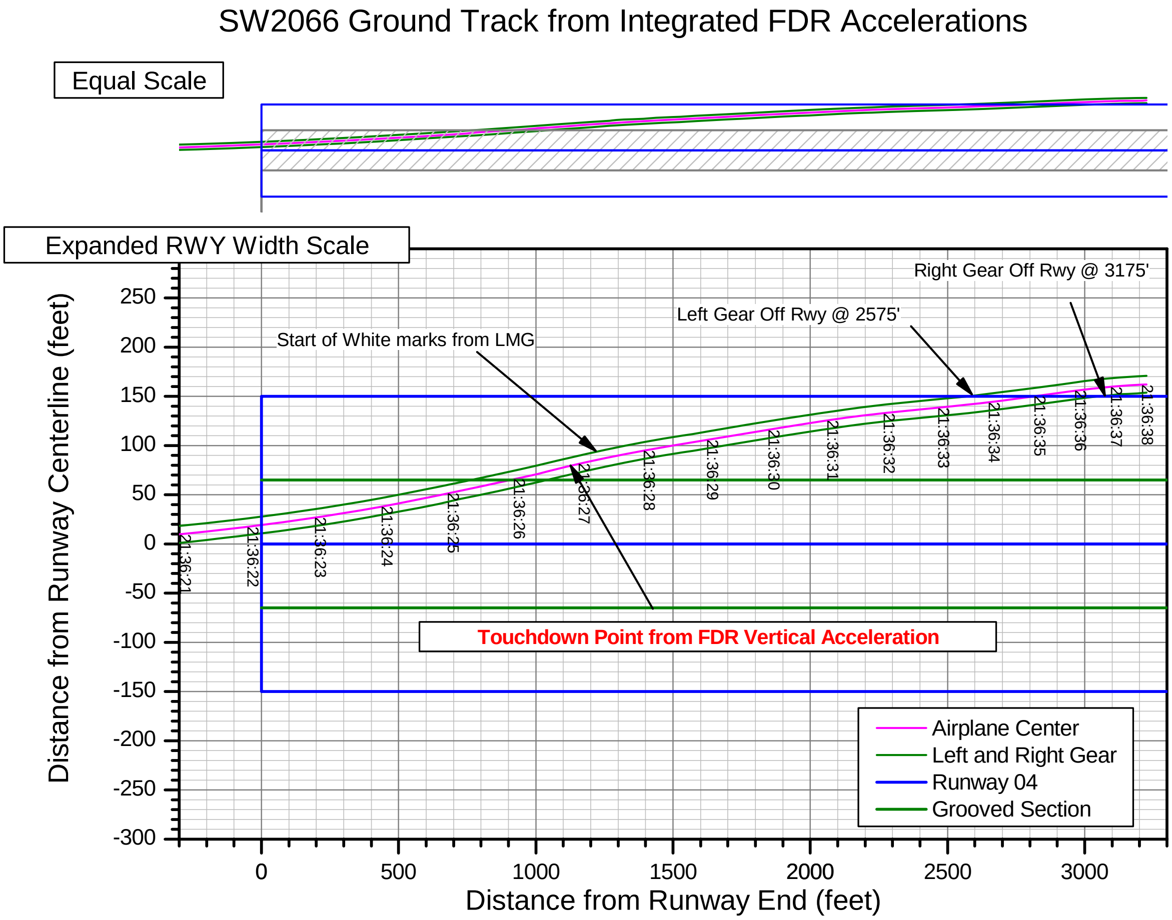

Figure 6. Integrated Ground Track During Approach and Landing.
Note: The lower part of the diagram uses an expanded runway width scale to portray lateral deviations from the runway centerline.

Because the FDR-recorded winds were calculated assuming coordinated flight with no sideslip, which did not account for short-term variations, winds were kinematically calculated from the FDR data to account for airplane angle-of-attack[27] and sideslip angle. The calculated winds and FDR winds were consistent for the approach until the airplane generated a nose-right sideslip angle shortly before touchdown. The wind direction and magnitude differences between the recorded and calculated data were greatest during the last 4 seconds before touchdown.

The calculated track indicated the airplane followed the glideslope and localizer beams with the autopilot engaged during the approach. Headwinds and crosswinds

[27] Angle-of-attack is the angle formed by the chordline of the wing and the direction of the air striking the wing.

varied, but the airspeed fluctuations during the approach were consistent with gusty winds, and the crosswind component was predominately from the left. While the autopilot was engaged, the roll attitude oscillated between ± 5°, control wheel inputs varied ± 20°, and the FDR recorded several vertical acceleration variations between 0.81 G and 1.31Gs.

Between 2136:01 and 2136:08, FDR data showed that the airplane encountered a headwind loss of 10 knots followed by a headwind increase of 10 knots. During the change in headwind and subsequent autopilot control inputs, the vertical acceleration decreased to 0.7 G, increased to 1.3 Gs, decreased to 0.7 G, and then increased to 1.0 G. During this time, the descent rate increased to about 1,200 feet per minute (fpm) and the engine N_1[28] (thrust) increased from 30 to 67 percent, coinciding with the airplane reaching the approach speed of 141 knots. FDR data indicated that the flight crew then disconnected the autopilot at 2136:11 at an altitude of about 145 feet agl. Ground track calculations showed the airplane track was approximately aligned with the runway centerline at this time.

About 1 second after the autopilot was disconnected, the airplane rolled to about 5° left wing down. The airspeed decreased to 136 knots, then increased to 148 knots with a concurrent pitch decrease from 4.2° to 1.4°. About 2136:21, the airplane flare was initiated with a small airplane-nose-up column command when the airplane was about 50 feet agl. At this time, the airplane was descending at a rate of about 720 fpm.

The airplane's roll attitude varied between 2° and 6° left wing down, and the airplane's calculated ground track angle changed from 37.5° to 32° (runway 4 centerline is 37.4°) after autopilot disconnect. The calculated winds showed a shift in direction, yielding a headwind increase of about 6 knots and a left crosswind decrease of about 6 knots. The airplane heading remained at 34.5°, and right rudder increased to 8.3° by 2136:26 as the airplane continued to track to the left of runway centerline. One second before touchdown, 5° of airplane-nose-up column was commanded, which arrested the airplane-nose-down pitch rate before the airplane touched down and increased the airplane's pitch attitude from 1.2° to 3.7°. The descent rate decreased to 300 fpm. Concurrently, N_1 began to decrease from 67 percent to idle, and a right control wheel input brought the wings to level.

The airplane touched down with a descent rate of about 570 fpm and with a ground track angle left of the runway heading. Touchdown occurred at 2136:27 with a vertical acceleration of 2.1 Gs as the roll attitude was brought back to wings level. Ground track calculations showed the airplane touched down about 1,200 feet beyond the runway threshold and about 75 feet to the left of the runway centerline. Tire marks and ground track calculations indicated the airplane continued to track to the left of runway centerline after landing. As the airplane tracked to the left, the rudder input was increased to the right, which changed the airplane's heading to 40° until just before it went off the

[28] N_1 is the rotational speed of the low-pressure compressor in a dual-spool gas turbine engine.

runway, when the heading was realigned with the runway heading. Ground track information indicated the left main landing gear went off the runway surface about 2,575 feet from the threshold.

FDR longitudinal acceleration data after touchdown and before application of reverse thrust showed a deceleration rate of about 0.3 G while the airplane was on the runway, starting about 2.5 seconds after touchdown. According to the Aircraft Performance Group calculations, a deceleration of 0.3 G is equivalent to an autobrake setting between three and max[29] and was consistent with the airplane achieving brake friction with the runway surface. The deceleration rate increased to about 0.6 G as reverse thrust was applied, and the airplane went off the side of the runway. FDR acceleration information, CVR data, and ground track calculations indicated the airplane went off the runway surface about 7 seconds after the initial touchdown.

ORGANIZATIONAL AND MANAGEMENT INFORMATION

Southwest, based in Dallas, Texas, is certified to operate as an air carrier and conduct common carrier operations under the provisions of 14 CFR Part 121. The airline began service on June 18, 1971. At the time of the accident, the airline employed 4,151 pilots, 7,262 flight attendants, and 2,335 mechanics and inspectors. It had a fleet of 375 Boeing 737 airplanes.

Company Procedures for Thunderstorm Avoidance

Southwest's Flight Operations Manual (FOM), Supplemental Procedures, Weather Procedures, section 4.3, "Flight in the Vicinity of Thunderstorms," page 47 (dated January 3, 2002), stated the following, in part, regarding thunderstorm avoidance:

> When a flight encounters or anticipates encountering hazardous meteorological conditions, the captain should exercise sound judgment and utilize all available resources, including airborne weather radar, ground tracking radar, and pilot reports to minimize hazardous weather encounters.
>
> The following questions can help identify hazardous weather associated with thunderstorms. As a general rule of thumb, the higher the number of "YES" answers, the higher the threat and the greater the avoidance distances should be.

[29] According to Boeing, an autobrake setting of between three and max is the equivalent of a deceleration of 7.2 feet per second (0.224 G) and 14 feet per second (0.435 G) over 80 knots and 7.2 feet per second and 12 feet per second (0.373 G) under 80 knots. The autobrake system, working together with the antiskid system, automatically applies brake pressure at the deceleration level selected by the pilot. The system maintains a constant deceleration level throughout the landing roll. The only higher setting beyond max is for a rejected takeoff, when full brake pressure is applied.

Is the local atmosphere significantly unstable?

Is the dew point greater than 10 degrees C?

Is the temperature/dew point spread greater than 17 degrees C?

Is the weather moving at greater than 10 knots?

Is there visible evidence of a hazard?

Is this the southernmost cell in a line?

Is the cell greater than 15,000 feet tall?

Is the gradient and shape of the cell asymmetrical?

Is it casting a shadow?

The following procedures should be considered when hazardous meteorological conditions are encountered or anticipated:

Deviation from the prescribed route and/or diversion to an alternate airport.

The use of airborne weather radar primarily as an indicator of storm location for avoidance purposes rather than a locator of "soft spots" for penetration.

Advise passengers to keep their seatbelts fastened at all times. Advise the flight attendants of anticipated conditions.

If knowledge of conditions is essential to the safety of other flights, the captain will notify the nearest ATC facility and the dispatcher.

Southwest's FOM, section 4.3, page 48, "Thunderstorm Avoidance Guidelines," states the following:

Use the following guidelines to avoid flight near or through thunderstorm activity:

When the temperature at flight level is 0 degrees Celsius or higher, avoid all echoes by 5 nautical miles.

When the temperature at flight level is less than 0 degrees Celsius, avoid all echoes by 10 nautical miles.

Avoid all echoes by 20 nautical miles if the aircraft clears the tops by less than 5,000 feet. All weather with radar tops of 15,000 feet may be hazardous.

All weather with radar tops above 20,000 feet is hazardous.

When flying above 23,000 feet, avoid all echoes by 20 nautical miles.

Never fly near an echo with a radar top above 30,000 feet.

If possible circumnavigate echoes by flying on the upwind side.

Circumnavigate all echoes with steep or asymmetrical gradients.

Assume that all magenta radar returns are severe thunderstorms.

NEVER assume that ATC will provide warning of hazardous weather.

NEVER assume that a PIREP will provide warning of hazardous weather.

NEVER continue flight toward a radar shadow.

Note: Although a general or severe thunderstorm may have a well-defined base, hazards often exist from the ground to the base of the convective cell, even in VMC [visual meteorological conditions].

Airborne Weather Radar Training and Guidance

The airplane was equipped with Bendix RDR-4B airborne weather radar with modes for weather, ground mapping, and turbulence. When the weather mode is selected, the radar displays the colors green, yellow, and red, which correspond to the following rainfall rates: green, 0.7 to 4 millimeters (mm) per hour; yellow, 4 to 12 mm per hour; and red, greater than 12 mm per hour. The radar scope displays range rings and orientation from 0º to 60° left and right of the airplane's nose. The Bendix RDR-4B did not display ground speed, airplane heading, or a map overlay.

Airborne weather radar training on the Bendix RDR-4B was included in first officer, captain upgrade, and recurrent training curricula. The training included proper tilt adjustment, flight with inoperative weather radar, and thunderstorm avoidance.

The weather radar section in recurrent training included, in part, radar reflectivity, performance, precipitation, and proper tilt adjustment. The recurrent training manual stated, “proper tilt management is the SINGLE most important key element in effective radar usage. Continuously adjust the tilt so not to OVERSCAN or UNDERSCAN an echo. You must adjust the tilt every time you change altitude or change the range selection on the radar.” The training section also stated, “as you descend and get closer to your destination, select a smaller range. Adjust the tilt to paint a narrow band of ground return at the top of the radar screen. This ensures proper scanning of storms in the terminal area.”

An additional weather radar handbook, “Radar Made Easy,” was also used during Southwest training, and included information similar to that found in the training curricula for first officers, captain upgrades, and recurrent training. The information was used in class, was part of home reading assignments, and was included in flight crew FOMS. The handbook outlined the capabilities and limitations of the Bendix RDR-4B, addressed radar myths and hazards, and explained proper tilt management. The handbook stated, “improper tilt angle can cause the radar beam to miss the storm entirely, leaving you blind to the hazard.” The handbook also stated, “when the radome is wet, attenuation occurs. The radar’s ability to operate effectively is DEGRADED.”

ADDITIONAL INFORMATION

Flight Crew Decision Errors Study

The National Aeronautics and Space Administration (NASA) analyzed data in a 1994 Safety Board study[30] of the most common flight crew decision errors to determine error patterns. The NASA study[31] found that the most common decision errors occurred when the flight crew decided to “continue with the original plan of action in the face of cues that suggested changing the course of action.” The study determined that “ambiguous cues may permit multiple interpretations. If this ambiguity is not recognized, the crew may be confident that they have correctly interpreted the problem. Even if the ambiguity is recognized, a substantial weight of evidence may be needed to change the plan being executed.”

Weather-Related Air Traffic Control Procedures

FAA Order 7110.65, “Air Traffic Control,” contains guidance for controllers on the distribution of weather information. Paragraph 2-6-2, “Hazardous Inflight Weather Advisory Service (HIWAS),” states, in part, the following:

[30] National Transportation Safety Board, *A Review of FlightcrewIinvolved Major Accidents of U.S. Air Carriers, 1978 Through 1990*, Safety Study NTSB/SS-94/01 (Washington, DC: NTSB, 1994).

[31] Orasanu, J.; Martin, L.; and Davison, J. *Errors in Aviation Decision Making: Bad Decisions or Bad Luck?* NASA Ames Research Center, Moffett Field, California. Presented to the Fourth Conference on Naturalistic Decision Making, Warrenton, Virginia, May 29-31, 1998.

> Controllers shall advise pilots of hazardous weather that may impact operations within 150 nm of their sector or area of jurisdiction. Hazardous weather information contained in HIWAS broadcasts includes: Airmen's Meteorological Information (AIRMET), Significant Meteorological Information (SIGMET), Convective SIGMET (WST), Urgent Pilot Weather Reports (UUA), and Center Weather Advisories (CWA). Facilities shall review alert messages to determine the geographical area and operational impact for hazardous weather information broadcasts.

The order adds that "terminal facilities have the option to limit hazardous weather information broadcasts as follows: tower cab and approach control facilities may opt to broadcast hazardous weather information alerts only when any part of the area described is within 50 nm of the airspace under their jurisdiction."

Paragraph 2-9-2, "Operating Procedures," provides guidance to tower controllers on the use and content of ATIS broadcasts. The Order states, in part, the following:

> Maintain an ATIS message that reflects the most current arrival and departure information…[and make a new recording] upon receipt of any new official weather regardless of whether there is or is not a change in values; [and] when runway braking action reports are received that indicate runway braking is worse than that which is included in the current ATIS broadcast.

The paragraph adds the following:

> Controllers shall ensure that pilots receive the most current pertinent information. Ask the pilot to confirm receipt of the current ATIS information if the pilot does not initially state the appropriate ATIS code. Controllers shall ensure that changes to pertinent operational information are provided after the initial confirmation of ATIS information is established. Issue the current weather, runway in use, approach information, and pertinent NOTAMs [notices to airmen] to pilots who are unable to receive the ATIS.

Paragraph 2-9-3, "Content," states, in part, that an ATIS broadcast should include the following, as appropriate:

> Airport/facility name, phonetic letter code, time of weather sequence (UTC). Weather information consisting of wind direction and velocity, visibility, obstructions to vision, present weather, sky condition, temperature, dew point, altimeter, a density altitude advisory when appropriate, and other pertinent remarks included in the official weather observation. Wind direction, velocity, and altimeter shall be reported from

> certified direct reading instruments. Temperature and dew point should be reported from certified direct reading sensors when available. Always include weather observation remarks of lightning, cumulonimbus, and towering cumulus clouds.
>
> NOTE - ASOS/AWOS [automated weather observing system] is to be considered the primary source of wind direction, velocity, and altimeter data for weather observation purposes at those locations that are so equipped.

Runway Friction Information

Three types of friction loss can occur on a wet runway surface, according to a senior research engineer at NASA's Langley Research Center. The NASA engineer, who testified at the Safety Board's public hearing on the June 1, 1999, accident involving American Airlines flight 1420 in Little Rock, Arkansas,[32] identified the friction loss types as viscous hydroplaning,[33] dynamic hydroplaning,[34] and reverted rubber skidding (or locked tires).[35]

In his public hearing testimony, the NASA engineer outlined the following conditions and factors for each friction loss type:

- The contributing factors for viscous hydroplaning are a damp or wet pavement, medium to high speed, poor pavement texture, and worn tire tread.
- The contributing factors for dynamic hydroplaning are a flooded pavement, high speed, low tire pressure, and worn tire tread.
- The contributing factors for reverted rubber skidding are a wet or flooded pavement, high speed, poor pavement texture, and a deficient brake system.

The NASA engineer stated that dynamic hydroplaning was not a factor in the Little Rock accident because of the scrub marks on the runway. He stated the scrub

[32] National Transportation Safety Board, *Runway Overrun During Landing, American Airlines Flight 1420, McDonnell Douglas MD-82, N215AA, Little Rock, Arkansas*, June 1, 1999, Aircraft Accident Report NTSB/AAR-01/02 (Washington, DC: NTSB, 2001). This accident report can be found on the Safety Board's Web site at <http://www.ntsb.gov>. The Board held a public hearing on this accident from January 26 to 28, 2000, in Little Rock.

[33] According to the article, "Landing on Slippery Runways," in Boeing's October to December 1992 *Airliner* magazine, "viscous hydroplaning occurs on all wet runways and is a technical term used to describe the normal slipperiness or lubricating action of the water." The article also stated that viscous hydroplaning reduces friction but not to the level that would prevent an airplane's wheel from spinning up shortly after touchdown.

[34] According to the article, "Landing on Slippery Runways," in Boeing's October to December 1992 *Airliner* magazine, dynamic hydroplaning "lifts the tire completely off the runway and causes such a substantial loss of tire friction that wheel spin up may not occur."

[35] The terms "reverted rubber skidding" and "reverted rubber hydroplaning" can be used interchangeably.

marks, which were white-appearing tracks on the pavement that were lighter in color than the adjacent areas, resulted from the high pressure between the tire print and the wet pavement. He stated that the marks were caused by the braking action between the tire and the pavement and the steering forces being developed between the tire and the pavement. He stated that hydroplaning would not produce scrub marks because friction is reduced when the tire is lifted off the wet or flooded pavement.

Airborne Weather Radar Information

At the Safety Board's request, an industry expert in the operation and use of airborne weather radar equipment examined AMA's ground-based radar; observed weather information; and reviewed the flight crewmembers' statements about how they used the airborne weather radar, including what settings, and what weather displays the pilots recalled seeing depicted on the radar screen. The expert, who conducted radar weather training programs for airlines, corporate flight departments, and the military, stated the "Bendix RDR-4B is a low-powered system, and on a 20 nm displayed range, the pulse is only 6 microseconds. Relatively little energy is being transmitted in each pulse. In addition, under certain conditions of light rain, resulting from a wet radome, side lobes may develop, which reduce the energy going out in the main lobe. That, in turn, will reduce the ability of the radar to detect weather through weather." He stated the proper procedure is to lower "the tilt so ground was being painted to watch for radar shadows." He stated the "distance to which ground is painted with tilt down, compared to how far it should be painted, is an indication of how much attenuation is occurring."

The weather radar expert considered the possibility that the radar was "over-scanning the rain" with the tilt set at +2º or +3º, as the captain recalled. He stated that, because the airplane was descending, the radar would have "scanned a wide altitude range [during the approach and descent]." He stated that, at "one mile from touchdown, the beam would have been scanning an altitude of from less than 600 feet to 1,200 feet above the runway…[where ground radar indicated] heavy to very heavy rain over the runway throughout that time."

He stated, "had the crew been knowledgeable in the proper use of airborne weather, they would have lowered the tilt so ground was being painted to watch for radar shadows [an area where the rain and/or hail is so intense radar energy is failing to penetrate it]."

ANALYSIS

GENERAL

The captain and the first officer were properly certificated and qualified in accordance with applicable Federal regulations and company requirements. No evidence indicated any preexisting medical or behavioral conditions that might have adversely affected the flight crew's performance during the accident flight. Flight crew fatigue was not a factor.

The airplane was properly certificated and equipped in accordance with Federal regulations and approved procedures. No evidence indicated preexisting engine, system, or structural failures.

The AMA controller working the approach and tower positions was properly certificated and qualified in accordance with applicable Federal regulations and FAA requirements. The controller complied with FAA orders and procedures for handling the arrival and landing of the flight, provided timely and appropriate weather information to the flight crew, and notified ARFF crews in a timely manner with pertinent runway and airplane information. Because of reduced visibility caused by the thunderstorm's heavy rainfall, the controller never visually observed the airplane during the approach or after touchdown. The emergency response was also timely and professional. Thus, the tower controller and ARFF crews were not factors in the accident.

ACCIDENT SCENARIO

The Approach

The flight crew was aware that thunderstorms might be a factor on the approach to AMA. The preflight weather package the flight crew received at LAS included a TAF that forecasted thunderstorms and moderate rain for AMA. A Convective SIGMET included in the release package indicated an area of severe thunderstorms (with the possibility of 1-inch hail and wind gusts to 50 knots) that was located 50 miles west of AMA along the flight route, and this severe thunderstorm area was moving to the east at 30 knots.[36] CVR information also indicated the flight crew was aware of thunderstorms along the approach and at the airport, and the crewmembers discussed their concerns about the weather with Southwest dispatchers, Southwest AMA base operations, and the AMA tower controller. Although the flight crew did not receive Convective SIGMET 8C, which expanded the area of indicated thunderstorms to include AMA while the flight was en route, the tower controller advised the flight crew several times of thunderstorm

[36] Convective SIGMET 8C, which included AMA and was issued at 0155, and Severe Thunderstorm Watch No. 429, was issued at 0140. It could not be determined if these were provided to the flight crew by Southwest dispatchers. Title 14 CFR 121.601 requires aircraft dispatchers to provide flight crews with "additional available information of meteorological conditions (including adverse weather phenomena, such as clear air turbulence, thunderstorms and low altitude wind shear)" during a flight.

activity at and near the airport. Finally, ATIS information Kilo, which was current at the time of the accident, indicated that a thunderstorm was at the airport. The contents of ATIS information Juliet, which was current from 0201 UTC to 0221 UTC when Kilo was issued, also included a thunderstorm advisory and was discussed with the controller at 2127. ATIS information Juliet and Kilo advised flight crews that hazardous weather information was available on HIWAS and from Fort Worth radio.

The flight crew also received weather information from the Bendix RDR-4B airborne weather radar and could see the storms outside the cockpit. The flight crewmembers stated they never lost sight of the airport, and the thunderstorms they were observing visually and on the weather radar appeared to be moving away from the airport. The captain stated he did not see any red returns on the radar, just "green with some yellow," indicating light to moderate rain. However, ground-based WSR-88D Doppler weather radar data indicated very strong to intense weather echoes that were present along the airplane's approach course at the time the airplane turned to the runway heading and intense weather echoes that were present near the approach end of runway 4 at the time of the accident. One radar scan indicated strong or greater echoes from about 3 nm southwest of the runway to the runway threshold. On the basis of these Doppler scans, the airborne weather radar should have displayed a red area in the runway 4 approach area about the time the airplane turned to runway heading.

Further, lightning strike data indicated continuous cloud-to-ground lightning (six flashes per minute) occurred within a 5-nm radius of the runway 4 threshold during the time the airplane was on the approach until the time of the accident, and seven cloud-to-ground strikes occurred near or along the flight's path during the approach. Although the strike lightning data were not available to the crew, CVR and FDR information indicated that the flight crew descended the airplane to avoid lightning. Turbulence was encountered, and FDR information indicated vertical accelerations between 0.7 G and 1.3 Gs and frequent roll and pitch angle oscillations, which were indicative of potentially hazardous or severe weather conditions. The flight crew had sufficient weather information to anticipate the likelihood of hazardous weather at the time of the arrival in AMA.

The investigation considered whether the airborne weather radar's setting or atmospheric conditions (attenuation caused by moisture on the radome) could have affected the radar's performance and influenced the flight crew's decision to proceed.[37]

The captain stated he saw thunderstorm activity on the airborne weather radar at the 160- and 20-mile range, but the thunderstorms appeared to be about 10 miles past the airport. He stated he had progressed down the ranges of the weather radar, and the antenna setting (tilt) was about 2° to 3° up at the 20-mile setting. However, the captain's

[37] The airplane's airborne radar unit was not examined after the accident. However, the flight crew's statements about its settings and returns were consistent with the unit functioning within its parameters. A review of maintenance logs for the airplane indicated that no maintenance had been accomplished on the radar unit before or after the accident.

descriptions of the airborne radar depictions did not comport with the strong weather echoes recorded by WSR-88D Doppler weather radar observations along the approach course and at the airport or with the controller's observations.

Although it is possible that attenuation resulted in flight crew decisions based on inaccurate airborne weather information, ground-based WSR-88D Doppler radar and CVR information indicated that light rain was first encountered during final approach and had increased in intensity on short final, which is a period when the flight crew would have been focused outside the cockpit and concentrating on completing a visual approach and landing. On the basis of flight crew statements, the crew's attention throughout the approach was focused outside the cockpit, which might account for the discrepancy between what the flight crew reportedly observed on the airborne weather radar and information indicated by Doppler radar and the controller. Even if the weather radar did not indicate a thunderstorm at the airport (because of attenuation), or if the flight crew overlooked or misinterpreted the weather radar information while en route and on the approach, frequent lightning along the approach course and turbulence should have alerted the crew to hazards related to convective weather along the approach course and at the airport.

Although the lack of specific airport location and other navigation information on the radar display (other than range ring and degree orientation off the airplane's nose) could have made it more difficult for the flight crew to correlate the echoes observed on the radar display with the airport location, the flight crew should have had sufficient information, including frequent weather updates from the controller (including an advisory that a thunderstorm was at the airport) and the view from the cockpit, to determine that hazardous weather was near or at the airport.

Thus, despite encountering continuous lightning and turbulence and receiving an update from the controller that a thunderstorm was at the airport, the flight crew continued the approach. These cues, collectively, should have increased the flight crew's awareness that the approach and landing at AMA were becoming more challenging and hazardous. Although the flight crewmembers briefed the approach and completed the approach and descent checklist, they did not consider or discuss additional options in the event of deteriorating weather conditions, such as holding until the thunderstorm moved away from the airport. The flight crew noted only during the missed approach briefing that the prescribed climbing right turn for a missed approach might not be possible because of the weather, which was an indication that the safety of conducting a missed approach had been compromised by severe weather near the airport.

Safety Board investigations of flight crew error-related accidents, including the investigation of the American Airlines flight 1420 accident in Little Rock, and NASA's study of flight crew error patterns found that the most common decision errors occurred when the flight crew decided to "continue with the original plan of action in the face of cues that suggested changing the course of action." During its investigation of the flight 1420 accident, the Board determined there was a need to enhance flight crew recognition of cues associated with severe thunderstorm activity and to establish guidance to improve flight crew decision-making when severe convective activity is present.

The flight crewmembers' decision to land could have contributed to their failure to respond conservatively to cues of deteriorating weather conditions in the terminal area, thus reducing their margins of safety. Although the flight crew did not lose sight of the airport during the approach and visibility did not deteriorate until the airplane encountered heavy rain on short final, the flight crew should have considered abandoning the approach.

Final Approach and Landing

The airplane flew a stabilized, autopilot-coupled ILS final approach to runway 4. During the approach, the autopilot compensated for nose-left drift angles several times and realigned the airplane with the runway heading. FDR-derived wind information indicated the crosswind was primarily from the left during the approach, descent, and landing. FDR and CVR information indicated that the autopilot was disengaged at 2136:11, when the airplane was at an altitude of 145 feet agl and 2,750 feet from the runway threshold, and that the remainder of the landing was conducted manually. After autopilot disconnect, small changes in headwind and crosswind values required flight control corrections by the flight crew.

Just before touchdown, the calculated winds showed a shift in direction, yielding a headwind increase of about 6 knots and a left crosswind decrease of about 6 knots. However, control inputs were maintained to correct for the left crosswind. The airplane crossed the threshold approximately over the centerline but was tracking to the left with a heading of about 34.5°, according to FDR information (the runway heading was 37.4°). Although a right control wheel input brought the wings level just before touchdown, right rudder movement (increasing to 8.3°) during the last 5 seconds before touchdown was not sufficient to realign the airplane's track with the runway heading. Without a sufficient control input change to account for the decreasing crosswind, the airplane continued to track to the left of the runway centerline. FDR information indicated the airplane's ground track angle was about 5° to the left of the runway centerline at touchdown.

AMA, which is located in an area known for convective activity and heavy rain, accommodates hundreds of civilian and military landings each year without incident. Although the flight crewmembers made a poor decision to land, which increased their workload, landing a transport-category airplane in the weather conditions they encountered (shifting wind conditions and reduced visibility) should be within the skill and performance levels expected of a professional line flight crew. This expectation includes landing the airplane on or very near the runway centerline and with the nose and ground track aligned with the runway heading. Evidence revealed the first officer failed to react in a timely manner to a decrease in crosswind conditions after autopilot disconnect and failed to initiate sufficient control adjustments to keep the airplane's track aligned with the runway heading at touchdown.

Although runway 4, which, at 300 feet wide, was nearly twice the width of many runways for transport-category aircraft, the flight crew had sufficient cues (high-intensity runway edge lights and a medium-intensity approach lighting system with runway alignment indicator lights) to keep the airplane aligned with the runway.

The Landing Roll

Performance and ground track calculations indicated the airplane touched down about 1,200 feet from the runway threshold and about 75 feet left of the centerline. Performance calculations, runway marks, and ground scars indicated the airplane continued to track left after landing, and the left main landing gear went off the runway surface about 2,575 feet from the threshold 7 seconds after initial touchdown.

During the Safety Board's public hearing on the American Airlines flight 1420 accident at Little Rock, a NASA engineer testified that such white or scrub marks on the runway were the result of high pressure between the tire print and the wet pavement and were caused by the braking action between the tire and the pavement. He noted that hydroplaning would not produce scrub marks because friction is reduced when the tire is lifted off the wet or flooded pavement.

FDR longitudinal acceleration data indicated that, after touchdown, the deceleration rate was about 0.3 G while the airplane was on the pavement, and braking action was achieved about 2.5 seconds after initial touchdown. According to Boeing, the airplane's deceleration rate of 0.3 G was equivalent to an autobrake setting between three and max. Safety Board aircraft performance group calculations indicated this deceleration was consistent with substantial braking action and friction with the runway surface. Although white scrub marks on the runway can be caused by viscous (reverted rubber) hydroplaning, there was no evidence of reverted rubber on the runway, and viscous hydroplaning would not produce the deceleration recorded by the FDR.

The accident airplane's landing was compared with the descent rates, airspeeds, and longitudinal accelerations (and decelerations) from four previous landings recorded on the FDR. Landing rolls before thrust reverser deployment were also examined. The examination determined that, before thrust reverser deployment, the airplane's deceleration was the result of braking action alone. The comparison with previous landings further indicated that the accident airplane's deceleration before thrust reverser deployment was greater than that for the previous four landings. Thus, the evidence indicates that the airplane was decelerating as the result of braking action, and dynamic hydroplaning did not occur during the accident airplane's landing roll. Moreover, even though the landing was to the left of the runway centerline, a sufficient runway area remained for a normal roll if the airplane's track had been aligned with the runway heading. Given the absence of significant runway surface and airplane braking system factors, evidence indicates that the flight crew failed to maintain directional control after initial touchdown and during the landing roll and allowed the airplane to continue to track left, which resulted in the runway excursion.

PROBABLE CAUSE

The probable cause of this accident was the flight crew's failure to align the airplane's ground track with the runway centerline before touchdown and the flight crew's failure to maintain directional control of the airplane after touchdown. Contributing to the accident was the flight crew's decision to continue the approach and to land with a thunderstorm (with associated gusty and variable winds) reported at the airport and the heavy rain, which reduced the flight crew's visibility on short final.