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NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

DELTA AIR LINES, INC.,
LOCKHEED L-1011-385-1, N726DA
DALLAS/FORT WORTH -
INTERNATIONAL AIRPORT, TEXAS
AUGUST 2, 1985

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16. Abstract On August 2, 1985, at 1805:52 central daylight time, Delta Air Lines flight 191, a Lockheed L-1011-385-1, N726DA, crashed while approaching to land on runway 17L at the Dallas Fort Worth International Airport, Texas. While passing through the rain shaft beneath a thunderstorm, flight 191 entered a microburst which the pilot was unable to traverse successfully. The airplane struck the ground about 6,300 feet north of the approach end of runway 17L, hit a car on a highway north of the runway killing the driver, struck two water tanks on the airport, and broke apart. Except for a section of the airplane containing the aft fuselage and empennage, the remainder of the airplane disintegrated during the impact sequence, and a severe fire erupted during the impact sequence. Of the 163 persons aboard, 134 passengers and crewmembers were killed; 26 passengers and 3 cabin attendants survived.

The National Transportation Safety Board determines that the probable causes of the accident were the flightcrew's decision to initiate and continue the approach into a cumulonimbus cloud which they observed to contain visible lightning; the lack of specific guidelines, procedures, and training for avoiding and escaping from low-altitude wind shear; and the lack of definitive, real-time wind shear hazard information. This resulted in the aircraft's encounter at low altitude with a microburst-induced, severe wind shear from a rapidly developing thunderstorm located on the final approach course.

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Adopted: August 15, 1986

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LOCKHEED L-1011-385-1, N726DA,
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SYNOPSIS

On August 2, 1985, at 1805:52 central daylight time, Delta Air Lines flight 191, a Lockheed L-1011-385-1, N726DA, crashed while approaching to land on runway 17L at the Dallas/Fort Worth International Airport, Texas. While passing through the rain shaft beneath a thunderstorm, flight 191 entered a microburst which the pilot was unable to traverse successfully. The airplane struck the ground about 6,300 feet north of the approach end of runway 17L, hit a car on a highway north of the runway killing the driver, struck two water tanks on the airport, and broke apart. Except for a section of the airplane containing the aft fuselage and empennage, the remainder of the airplane disintegrated during the impact sequence, and a severe fire erupted during the impact sequence. Of the 163 persons aboard, 134 passengers and crewmembers were killed; 26 passengers and 3 cabin attendants survived.

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1. FACTUAL INFORMATION

1.1 History of the Flight

On August 2, 1985, Delta Air Lines (Delta) flight 191 was a regularly scheduled passenger flight between Fort Lauderdale, Florida, and Los Angeles, California, with an en route stop at the Dallas/Fort Worth International Airport, Texas (DFW Airport). Flight 191, a Lockheed L-1011-385-1 airplane, departed Fort Lauderdale on an instrument flight rules (IFR) flight plan with 152 passengers and a crew of 11 on board at 1510 eastern daylight time. The DFW Airport terminal weather forecast contained in the flightcrew's dispatch document package stated, in part, that there was a possibility of widely scattered rain showers and thunderstorms, becoming isolated after 2000 central daylight time. 1/ The dispatch package also contained company Metro Alert No. T87, valid to 2100, which stated that "an area of isolated thunderstorms is expected over Oklahoma and northern and northeastern Texas . . . a few isolated tops to above

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1/ All times herein are central daylight based on the 24-hour clock.

FL 450." 2/ The flightcrew had reviewed this data before takeoff and did not call Delta's weather facility in Atlanta, Georgia, for any additional weather information.

The flight was uneventful until passing New Orleans, Louisiana. A line of weather along the Texas-Louisiana gulf coast had intensified. The flightcrew elected to change their route of flight to the more northerly Blue Ridge arrival route to avoid the developing weather to the south. This change necessitated a 10- to 15-minute hold at the Texarkana, Arkansas, VORTAC 3/ for arrival sequencing at the DFW Airport.

At 1735:26, the airplane's cockpit voice recorder (CVR) showed that the flightcrew received the following Automatic Terminal Information Service (ATIS) 4/ broadcast:

> DFW arrival information romeo, two one four seven Greenwich, weather six thousand scattered, two one thousand scattered, visibility one zero, temperature one zero one, dew point six seven, wind calm, altimeter two niner niner two, runway one eight right one seven left, visual approaches in progress, advise approach control that you have romeo.

At 1735:33, Fort Worth Air Route Traffic Control Center (ARTCC) cleared flight 191 to the Blue Ridge, Texas, VORTAC for the Blue Ridge Nine arrival, 5/ and to begin its descent.

At 1743:45, Fort Worth ARTCC cleared flight 191 to descend to 10,000 feet, 6/ gave it a 29.92 in Hg altimeter setting, and suggested that the flight turn to a heading of 250° "to join the Blue Ridge zero one zero radial inbound and we have a good area there to go through." The captain replied 7/ that he was looking at a "pretty good size" weather cell, "at a heading of two five five . . . and I'd rather not go through it, I'd rather go around it one way or the other." Fort Worth ARTCC then gave the flight another heading and stated "when I can I'll turn you into Blue Ridge, it'll be about the zero one zero radial." At 1746:50, the center cleared flight 191 direct to Blue Ridge and to descend to 9,000 feet, and flight 191 acknowledged receipt of the clearance.

At 1748:22, the captain told the first officer, "You're in good shape. I'm glad we didn't have to go through that mess. I thought sure he was going to send us through it." At 1751:19, the flight engineer said, "Looks like it's raining over Fort Worth." At 1751:42, Forth Worth ARTCC instructed flight 191 to contact DFW Airport Approach Control (Regional Approach Control), and at 1752:08, the flight contacted approach control stating that it was descending through 11,000 feet and had received ATIS Information Romeo. At 1756:28, Regional Approach Control's Feeder East controller transmitted an all aircraft message which was received by flight 191. The message stated in part,

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2/ A level of constant atmospheric pressure related to a reference datum of 29.92 in Hg. Each flight level is stated in three digits that represent hundreds of feet. FL 450 represents a barometric altimeter reading of 45,000 feet.

3/ VORTAC--A collocated very high frequency omni range station and ultra-high frequency tactical air navigational aid providing azimuth and distance information to the user.

4/ ATIS--A continuous broadcast of recorded weather and noncontrol airport information.

5/ A published Standard Arrival Route (STAR).

6/ All altitudes herein are mean sea level unless otherwise specified.

7/ Identification of the crewmembers speaking was made by members of the Cockpit Voice Recorder (CVR) Group familiar with the flightcrew.

"Attention, all aircraft listening . . . there's a little rainshower just north of the airport and they're starting to make ILS [instrument landing system] approaches . . . tune up one oh nine one for one seven left."

At 1759:47, the first officer stated, "We're gonna get our airplane washed," and at 1759:54, the captain switched to Regional Approach Control's Arrival Radar-1 (AR-1) frequency and told the controller that they were at 5,000 feet. AT 1800:36, the approach controller asked American Air Lines flight 351 if it was able to see the airport. (Flight 351 was two airplanes ahead of flight 191 in the landing sequence for runway 17L.) Flight 351 replied, "As soon as we break out of this rainshower we will." The controller then told flight 351 that it was 4 miles from the outer marker, and to join the localizer at 2,300 feet; the controller then cleared the flight for the ILS approach to runway 17L. All of the transmissions between the controller and flight 351 were recorded on flight 191's CVR.

At 1800:51, the approach controller asked flight 191 to reduce its airspeed to 170 knots indicated (KIAS), and to turn left to 270°; flight 191 then acknowledged receipt of the clearance. Flight 191 had been sequenced behind a Learjet Model 25 (Lear 25) for landing on runway 17L.

At 1802:35, the approach controller told flight 191 that it was 6 miles from the outer marker, requested that it turn to 180° to join the localizer at or above 2,300 feet, and stated, "cleared for ILS one seven left approach." The flight acknowledged receipt of the transmission. At 1803:03, the approach controller requested flight 191 "to reduce your speed to one six zero please," and the captain replied, "Be glad to." Thereafter, at 1803:30, he broadcast, "And we're getting some variable winds out there due to a shower . . . out there north end of DFW." This transmission was received by flight 191, and at 1803:34, the CVR's cockpit area microphone (CAM) showed that an unidentified flightcrew member remarked, "Stuff is moving in."

At 1803:46, the approach controller requested flight 191 to slow to 150 KIAS, and to contact the DFW Airport tower. At 1803:58, the captain, after switching to the tower's radio frequency, stated, "Tower, Delta one ninety one heavy, out here in the rain, feels good." The tower cleared the flight to land and informed it, "wind zero nine zero at five, gusts to one five." At 1804:07, the first officer called for the before-landing check. The flightcrew confirmed that the landing gear was down and that the flaps were extended to 33°, the landing flap setting.

At 1804:18, the first officer said, "Lightning coming out of that one." The captain asked, "What," and the first officer repeated "Lightning coming out of that one." The captain asked, "Where," and at 1804:23, the first officer replied, "Right ahead of us."

Flight 191 continued descending along the final approach course. At 1805:05 the captain called out "1,000 feet." At 1805:19, the captain cautioned the first officer to watch his indicated airspeed and a sound identified as rain began. At 1805:21, the captain warned the first officer, "You're gonna lose it all of a sudden, there it is." At 1805:26 the captain stated, "Push it up, push it way up." At 1805:29, the sound of engines at high rpm was heard on the CVR, and the captain said "That's it."

At 1805:44, the Ground Proximity Warning System's (GPWS) 8/ "Whoop whoop pull up" alert sounded and the captain commanded "TOGA". 9/ At 1805:48 and 1805:49, two more GPWS alerts were recorded. At 1805:52 a sound similar to that produced by a landing airplane and the sound of the takeoff warning horn 10/ were recorded. At 1805:56, the local controller in the tower told flight 191 to "go around," and the CVR recording ended at 1805:58.

Witnesses on or near State Highway 114 north of the airport saw flight 191 emerge from the rain about 1.25 miles from the end of runway 17L and then strike an automobile in the westbound lane of State Highway 114. Subsequent investigation showed that the airplane had touched down earlier and became airborne again before striking the automobile.

The local controller handling flight 191 also saw it emerge from the rain at the north end of the field. He testified that,

> When Delta came out of the rain shower his attitude to me did not appear to be safe. As many aircraft as I've seen land in my years at DFW, normal attitude is nose slightly up . . . and when he appeared out of the rain he was in what appeared to be straight and level flight. It just didn't look right to me. (So I told the flight) just, 'Delta go around.' "

After the plane struck the car and a light pole on the highway, other witnesses saw fire on the left side of the airplane in the vicinity of the wing root. The witnesses generally agreed that the airplane struck the ground in a left-wing-low attitude, and that the fuselage rotated counterclockwise after the left wing and cockpit area struck a water tank on the airport. (See figures 1 and 2.) A large explosion obscured the witnesses' view momentarily, and then the tail section emerged from the fireball, skidding backwards. The tail section finally came to rest on its left side with the empennage pointing south and was subsequently blown to an upright position by wind gusts. One hundred and thirty-four persons on board the airplane and the driver of the automobile which was struck by the airplane were killed in the accident; 27 persons on board the airplane and 1 rescue worker at the accident site were injured, 2 passengers on the airplane were uninjured.

The accident occurred at 1805:52 during daylight hours at coordinates 32° 55'N latitude and 97°01'W longitude.

8/ The GPWS warns the flightcrew of a potentially dangerous flight path relative to the ground. The following abnormal flight conditions will produce a "Pull Up" warning: an excessive sink rate below 2,500 feet above the ground (AGL); excessive closure rate toward rising terrain; descent immediately after takeoff; not in landing configuration below 500 feet AGL; and excessive deviation below the ILS glide slope.

9/ TOGA - Takeoff/Go Around Switch. A pilot-actuated switch which, when selected and the airplane is being flown manually, provides flight director command bar guidance for an optimum climbout maneuver.

10/ A throttle-actuated warning system: If flaps, speed brakes, or stabilizer trim are not set correctly for takeoff, the takeoff warning horn will sound when the throttles are advanced. The same horn sounds on the ground if an elevator jam is detected and the throttles are retarded. When airborne, with gear and flaps up and below 180 KIAS, the system will provide an aural warning when the throttles are retarded to flight idle.

Figure 1.--Flight 191's ground track toward the water tanks.

Figure 2.--The aft section of the airplane's fuselage.

1.2 Injuries to Persons

Injuries 11/	Crew	Passengers	Others
Fatal	8	126	1*
Serious	1	14**	0
Minor	2	10	1***
None	0	2	0
Total	11	152	2

* Driver of the automobile struck by flight 191.
** Two survivors died more than 30 days after the accident.
*** An employee of an airline who assisted in rescuing survivors was hospitalized overnight for chest and arm pains.

1.3 Damage to the Airplane

The airplane was destroyed by impact and postcrash fire.

1.4 Other Damage

One automobile was destroyed, four highway light standards were knocked over, and two water storage tanks on the airport were damaged. The north water tank was dented and the south tank was buckled and displaced from its base.

1.5 Personnel Information

The flightcrew, cabin crew, and air traffic controllers were qualified in accordance with current regulations. The examination of the training records of all personnel did not reveal derogatory entries or anything unusual. (See appendix B.)

The investigation of the background of the flightcrew and their activities during the 2 to 3 days before reporting for the accident flight did not reveal anything remarkable. According to airmen who had flown with the captain, he was a very capable and meticulous pilot who adhered strictly to company procedures, explained his thoughts about airplane operation to the flightcrew, and cautiously deviated around thunderstorms even if other flights took more direct routes. He willingly accepted suggestions from his flightcrew and made prompt decisions. The captain's personnel file showed that he had been designated by the Federal Aviation Administration (FAA) to serve as a line check airman in the Boeing 727 and McDonnell Douglas DC-8 airplanes.

FAA surveillance records indicate that the captain had received eight en route inspections in the L-1011 since 1979, and all were satisfactory with favorable comments added concerning cockpit discipline and standardization.

11/ Section 49 CFR 830.2 of the Safety Board's rules defines a "fatality" and a "serious injury" as follows: "Fatal Injury" means any injury which results in death within 30 days of the accident. "Serious injury" means any injury which (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface.

Delta captains who had flown recently with the first officer described him as an above average first officer. They stated that he had excellent knowledge of the L-1011. For 2 years, beginning in September 1977, the first officer had worked with the company's L-1011 ground school instructors staff to revise completely Books I and II of the Delta Air Lines L-1011 Pilot Operating Manual. In October 1973, the FAA designated the first officer as a line and proficiency check airman in the L-1011 airplane.

Fellow company cockpit personnel described the second officer as observant, alert, and professional. He monitored the operation of the airplane and called attention to items he thought required it. He had a good knowledge of the airplane. He had served as second officer instructor and check airman on the Boeing B-727 airplane. FAA records for eight route inspections since April 1981 indicated satisfactory performance.

Interviews with the three air traffic control (ATC) controllers who had provided air traffic services to flight 191 during its descent and final approach to DFW Airport did not disclose anything either remarkable or out of the ordinary. The three controllers, two radar controllers, and local controller in the airport tower were full performance level (FPL) controllers and were fully qualified to staff their respective positions. (See appendix B.) Only one controller, the AR-1 controller had worked any overtime during the 2 weeks preceding the accident. He had worked overtime on July 30, 1986, and was off duty the following day.

1.6 Airplane Information

The airplane, a Lockheed L-1011-385-1, N726DA, was owned and operated by Delta. (See appendix C.) The airplane's maximum takeoff and landing gross weights were 430,000 pounds and 348,000 pounds, respectively. Based on the company's final weight data record contained in flight 191's dispatch documents, its estimated landing weight and center of gravity for landing at the DFW Airport were 324,800 pounds and 21.8 percent MAC (mean aerodynamic chord). The forward and aft center of gravity limits for landing were 17.1 percent MAC and 32.4 percent MAC. Based on the landing weight and with the flaps set at 33°, the calculated approach speed was 137 KIAS. 12/ The maximum allowable tailwind for takeoff and landing was 10 knots, and the maximum demonstrated landing crosswind was 35 knots.

Flight 191 had about 28,000 pounds of fuel when it began its approach. According to the flight plan, 12,300 pounds plus the required 11,000-pound reserve were required for the flight to the alternate airport, San Antonio, Texas, leaving 4,700 pounds of fuel for maneuvering in the DFW Airport area. At 3,000 feet, gear and flaps up, 4,700 pounds of fuel would have permitted the flight to hold about 20 minutes before departing for San Antonio.

N726DA was equipped with a Bendix model RDR-1F monochromatic weather radar system. The system operates on X-band frequency at a 3.2 cm wavelength. The system is designed to display targets at three range selections--50, 150, and 300 nautical miles (nmi)--and to display weather in two modes--normal and contour. In the normal mode, any precipitation return exceeding a radar reflectivity of 20 dBZ 13/ is displayed as a luminescent green area on the dark background of the plan position indicator (PPI). The stronger the reflectivity of the precipitation return, the stronger the return displayed on the PPI will be. When the radar system is placed in contour mode, the contour circuitry,

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12/ Approach, or reference speed (Vref), is a speed equal to 1.3 times the stall speed in a particular airplane configuration.

13/ dBZ: A measurement of radar reflectivity expressed in decibels.

in effect, inverts all levels of reflectivity above 40 dBZ and displays them as a black hole surrounded by luminescent green areas. The 40-dBZ reflectivity level corresponds approximately to a National Weather Service (NWS) level 3 radar echo (see section 1.7).

The display area of the PPI is about 3 1/2 inches in diameter. With a 50-nmi range selection, a weather cell with a diameter of 10 to 15 nmi would cover a diameter of 0.6 to 0.9 inch on the PPI. If the precipitation contained in the cell exceeded a 40-dBZ reflectivity, and the pilot selected contour mode, that part of the cell exceeding the 40-dBZ level would contour and appear as a black hole on the PPI. As the range between the airplane and the cell decreased, the dimensions of the cell portrayal would remain constant, but the portrayal would move downward toward the origin point of the antenna sweep at the bottom center of the PPI. If ground returns were being displayed on the PPI as the airplane approached the cell, the pilot would have to increase the antenna tilt until the ground returns were eliminated. As the airplane closed to within 2 nmi of the cell, the cell's radar return would begin to disappear at the base of the PPI.

The airplane's logbook showed that flightcrews had written up the weather radar system seven times between June 6 and July 25, 1985. The logbook entries also showed that corrective action had been accomplished after each flightcrew entry. After July 25, no further entries concerning the weather radar were found nor were any carry-over maintenance items on this system found.

1.7 Meteorological Information

The 1600 NWS surface analysis weather chart issued by the National Meteorological Center, Camp Springs, Maryland, showed a weak diffuse stationary front about 60 nmi north of the DFW Airport. The 1900 NWS surface analysis chart also showed a weak diffuse cold front about 60 nmi north of the DFW Airport.

The NWS terminal forecast for the DFW Airport pertinent to the accident indicated a slight chance of a thunderstorm with a moderate rain shower. The NWS area forecast pertinent to the accident called for isolated thunderstorms with moderate rain showers for northern and eastern portions of Texas. The terminal forecast was issued by the NWS Forecast Office in Fort Worth, Texas, and the area forecast was issued by the National Aviation Weather Advisory Unit in Kansas City, Missouri.

There were no SIGMETS, 14/ convective SIGMETs 15/, Severe Weather Warnings, Local Aviation Warnings, Severe Weather Watches, or Center Weather Advisories (CWA) in effect for the time and area of the accident.

The company's dispatch and meteorology department provided the flightcrew with a dispatch package which contained the following weather documents: the weather at DFW Airport and at the flight's field alternate, San Antonio; a DFW Airport terminal weather forecast indicating widely scattered moderate rain showers and thunderstorms with moderate rain showers; an en route forecast indicating isolated thunderstorms, moderate rain showers over Oklahoma and northern and northeastern Texas with a few isolated tops above 45,000 feet; and Delta Metro Alerts applicable to the route of flight. The forecasts were prepared by Delta meteorologists.

14/ A weather advisory concerning weather significant to the safety of all aircraft.
15/ Convective SIGMETs are issued by the National Aviation Weather Advisory Unit, Kansas City, Missouri, for lines of thunderstorms, severe/embedded thunderstorms of any intensity level, and for areas of 3,000 square miles or larger with VIP level 4 (see section 1.7.1) or greater covering at least 40 percent of the area.

1.7.1 Weather Radar Data

The weather radar antenna at the NWS station at Stephenville, Texas, is located about 72 nmi from the approach end of runway 17L at DFW Airport on a bearing of 55°. The Stephenville radar is a Weather Surveillance Radar (WSR) type 57M with Video Integrator Processor (VIP) equipment. The VIP equipment permits NWS radar observers to determine objectively the intensities of radar weather echoes. Based on this capability, the NWS has classified six levels of echo intensity and has assigned VIP numbers for each level. (See table 1.)

Table 1.--VIP levels and categories of intensity and rainfall rate.

VIP level	Echo intensity	Convective rainfall rate (in/hr)	dBZ (threshold values)
1	weak	0.05 - 0.2	30
2	moderate	0.20 - 1.1	30
3	strong	1.10 - 2.2	41
4	very strong	2.20 - 4.5	46
5	intense	4.50 - 7.1	50
6	extreme	> 7.1	57

Although existing NWS weather radar systems cannot detect turbulence, there is a correlation between the degree of turbulence and other weather features associated with thunderstorms and the intensity of the radar weather echo. The degree of turbulence and type of weather phenomena associated with these VIP levels have been identified and categorized. The resultant tabular data has been made available to pilots and controllers in various publications. The following table, excerpted from the Pilot/Controller Glossary of the June 6, 1985, Airmans Information Manual (AIM), presents the weather features likely to be associated with the VIP levels during thunderstorm weather situations.

Table 2.--Radar weather echo intensity levels.

1. Level 1 (WEAK) and Level 2 (MODERATE). Light to moderate turbulence is possible with lightning.

2. Level 3 (STRONG). Severe turbulence possible, lightning.

3. Level 4 (VERY STRONG). Severe turbulence likely, lightning.

4. Level 5 (INTENSE). Severe turbulence, lightning, organized wind gusts. Hail likely.

5. Level 6 (EXTREME). Severe turbulence, large hail, lightning, and extensive wind gusts.

Photographs taken of the Stephenville weather radar display were examined by a NWS Southern Region Radar Program Leader. The photographs were taken at 4- to 5-minute intervals between 1728 and 1813 and the program leader's examination revealed the following:

Between 1728 and 1743, two small pinpoint radar echoes appeared about 9 to 10 nmi northeast of the end of runway 17L; however, these two echoes disappeared by 1743.

At 1748, a VIP level 2 cell, hereinafter called Cell "C," developed about 6 nmi northeast of the end of runway 17L. By 1752, Cell "C" had intensified to a VIP level 3, and a new pinpoint radar echo, hereinafter called Cell "D," had developed south of Cell "C". Cell "D" was located about 2 nmi northeast of the end of runway 17L and its intensity was about VIP level 1.

At 1756, Cell "D" had intensified to about VIP level 3 and was located just north of the end of runway 17L. Cell "C" had not moved and its intensity "was not discernible."

At 1800, Cell "D," which appeared to be "the dominant echo," was still located near the end of runway 17L, and "appeared to be a VIP level 3." Cell "C" was "no longer displayed." By 1804, Cell "D" had intensified to a VIP level 4.

Stephenville Upper Air Radar Specialist.--The upper air radar specialist on duty at the time of the accident testified that he left his radar position about 1735 for dinner. The room in which he ate was equipped with a television monitor which displays the weather echo intensity from the Stephenville weather radar. The monitor uses different colors to portray the six VIP intensity levels. The radar specialist testified that he was able to and did monitor the presentation while he was eating.

At 1748, the radar specialist finished eating, but he did not return to the radarscope. Instead he tended to other duties and assisted another station specialist in preparing and launching a radiosonde ascent. 16/

About 1800, the radar specialist returned to the radar and saw a small weather cell (previously identified as Cell "D"). The top of the cell was 40,000 feet, and after measuring its intensity with the VIP equipment, the radar specialist testified that it was a "pinpoint four." He testified, "A pinpoint four means [that the cell was] barely a four intensity."

The radar specialist testified that Cell "D" was "in the area of [the airport]," but he could not state a precise distance. The weather radar did not have an internal map overlay, and in order to determine prominent geographical features, he had to put a paper overlay or a transparency on the [radar] scope." While the overlay used by the radar specialist included Dallas, Fort Worth, and other communities in the area, it did not include DFW Airport or other airports.

About 1804, the radar specialist called the Fort Worth Forecast Office, advised it of the presence of Cell "D," that it was a very strong echo, that the top was at 40,000 feet, and that he had observed the upper structure of the cell and had not found any severe weather in it (i.e., the cell's mid-level reflectivity was not equal to or greater than VIP level 4 and there was no mid-level overhang).

The radar specialist was not a meteorologist and was not qualified to issue either a forecast or a prediction as to whether Cell "D" would either dissipate or continue growing. He was not required to notify anyone when a thunderstorm was located near

16/ An instrument sent aloft to measure temperature, pressure, and humidity. Wind speed and direction information are obtained by tracking the radiosonde.

DFW Airport, nor was he required to notify either the Fort Worth ARTCC's Center Weather Service Unit or anyone at DFW Airport.

After notifying the Fort Worth Forecast Office, the radar specialist turned his attention to analyzing other radar echoes on his scope and did not redirect his attention to Cell "D" until about 1821. By that time, the top of Cell "D" had reached 50,000 feet and its intensity had increased to VIP level 5.

The radar specialist also testified that there was another small weather cell just north of Cell "D." He testified that it was hard to estimate the intensity level of the cell based on interpretation of the radar photographs portraying the cell, but based on the radar photograph taken at 1800, he said that "it looks like maybe a VIP [level] two." The radar specialist testified that, based on the radar photographs, he could not state that the clouds and rains of the small cell (Cell "C") would have masked the thunderstorm represented by Cell "D" from an airplane approaching DFW Airport from the north.

1.7.2 The Fort Worth NWS Forecast Office

The Fort Worth Forecast Office serves both the general public and the aviation community. At the time of the accident, the forecaster-in-charge of the office was also manning the aviation desk. The forecaster-in-charge testified that no special training "with regard to aviation" was required before being assigned to the aviation desk. He testified that it was called the aviation desk because the forecaster assigned to it handled "all aviation products: the terminal forecasts [and] the transcribed weather broadcasts."

The Forth Worth Forecast Office also was responsible for issuing Aviation Weather Warnings to the DFW Airport, and except for Carswell Air Force Base, to all airports in the Dallas/Fort Worth metropolitan area. Pursuant to a local letter of agreement between the forecast office and DFW Airport, the criteria for issuing an Aviation Weather Warning were a sustained wind of 35 knots or greater (1 minute), wind gusts of 40 knots or greater, and a severe thunderstorm/tornado warning for Tarrant and/or Dallas County.

According to the NWS forecaster-in-charge, terminal forecasts and Aviation Weather Warnings are transmitted from the forecast office to DFW Airport through their computer system. The computer data are transmitted to the contract weather observer's office on the airport. The contract weather observer in turn transcribes the data onto an electrowriter system which has terminals in the DFW Airport Tower, Delta Air Lines Operations, and other aviation organizations at DFW Airport. The forecaster-in-charge estimated that the time between the decision to issue an Aviation Weather Warning and its delivery to user organizations at the airport could vary from 6 to 10 minutes. He also testified that there was a dedicated or hot-line telephone between his office and the Center Weather Service Unit in the Fort Worth ARTCC but not to the DFW Airport Tower.

The Fort Worth Forecast Office also had a television monitor which was set to the Stephenville weather radar on the day of the accident. The monitor did not have any mapping capability and the overlays used by the forecasters to fix the geographical location of weather echoes did not depict DFW Airport. Nevertheless, the forecaster-in-charge testified that the meteorologists in the office could fix the location of the airport within 3 miles. According to the forecaster-in-charge, he did not see any weather echoes within 10 nmi of the DFW Airport on the Kavouras monitor until about 1750 or shortly thereafter.

The forecaster-in-charge testified that because the phone call from the Stephenville radar specialist at about 1804 was taken on the speaker by the public forecaster, the forecaster-in-charge overheard the radar specialist describe Cell "D" as a VIP level 4 weather echo with tops at 40,000 feet. The forecaster testified that he observed the cell on the television monitor. He estimated that it was a VIP level 3 to VIP level 4, but that he did not believe it was a storm of sufficient intensity to warrant issuing an Aviation Weather Warning.

According to the forecaster-in-charge, the intensity level of a weather echo "is merely an indication" of the severity of a storm. The forecaster testified, "Once we get a signature on the radar that suggests the possibility, we then seek ground truth." 17/According to the forecaster, in the absence of ground truth reports from observers attesting to the presence of either thunder, hail, or both, he would not label a VIP level 4 cell a thunderstorm. 18/ He also testified that either when or shortly after they received the telephone call from Stephenville, the forecast office began contacting their spotters in the area of Cell "D" for ground truth reports.

The forecaster-in-charge testified that if he observed a VIP level 5 or VIP level 6 echo out over a relatively thinly populated or uninhabited area, and the echo had increased rapidly over the past 20 minutes to 30 minutes, and if "it's moving toward a densely populated area, I would in all likelihood put out a warning on it." He further testified that if he were to observe a VIP level 4 echo moving toward the DFW Airport, "in all likelihood, I would do nothing with it." He testified that throughout the afternoon and early evening hours the meteorologists in the forecast office had observed a number of radar echoes similar to that of Cell "D," none of which had, based on ground truth reports, contained phenomena that met the criteria for issuing a warning to the DFW Airport. Cell "D" did not, in his judgment, seem any different from those cells observed earlier, and therefore he did not issue an Aviation Weather Warning to DFW Airport.

The forecaster-in-charge testified that if, in his judgment, 40-knot winds had been associated with Cell "D," he would have issued the required warning. However, based on what was produced by similar weather echoes in the same area during that afternoon and evening, "we had nothing to suggest that we were going to have winds of that magnitude. I elected, therefore, not to issue a warning." He also testified that an Aviation Weather Warning is not meant for aircraft in flight, but is meant for the airport itself. Its primary purpose is to alert airport personnel that tie-down precautions for airplanes and equipment may be required. The meteorologists in the forecast office did not become aware of a thunderstorm at DFW Airport until they received the DFW Airport's 1805 surface weather observation.

Before the onset of the thunderstorm at the airport, the maximum recorded winds were about 10 knots. The forecaster-in-charge testified that the first indication the forecast office had that the wind gusts exceeded 40 knots was when the contract weather observer at DFW Airport called at 1815 and reported that he had recorded wind gusts to 46 knots.

17/ A report from an individual describing what meteorological event is occurring at his or her observation point. The report could include rainfall intensity, the presence or lack of thunder and/or lightning, the presence or lack of hail and the size of the hail, and significant winds.

18/ Thunderstorm--In general, a local storm invariably produced by a cumulonimbus cloud, and always accompanied by lightning and thunder (Glossary of Meteorology: 1959).

Although the television monitor in the forecast office did not incorporate any geographical mapping capability and the overlays used in the forecast office to fix the geographical location of the weather echoes did not depict the location of the DFW Airport, the forecaster-in-charge testified that his decision not to issue aviation weather warnings was based solely on his assessment of the existing meteorological conditions and not on any uncertainty as to the location of DFW Airport.

1.7.3 The Fort Worth ARTCC's Center Weather Service Unit

The terms and conditions establishing a Center Weather Service Unit (CWSU) are contained in a Memorandum of Agreement among the Department of Transportation, the FAA, the National Oceanic and Atmospheric Association (NOAA), and the NWS as amended July 14, 1981. The agreement states that the NWS will operate CWSUs at selected ARTCCs and that,

> These units will each be comprised of four professional meteorologists operating two shifts per day except during periods of extended annual or sick leave as may be determined by the NWS. Operating hours shall be determined in consonance with the Chief of each ARTCC.

The agreement further states, in part, that the FAA will reimburse the NWS for the total personnel costs, including supporting services, relocation costs, and travel costs actually incurred for work performed under the Agreement. Under the terms of the agreement, the FAA could have chosen and received a higher level of staffing by meteorologists at the CWSU at the Fort Worth ARTCC.

The duties and responsibilities of a CWSU are contained in FAA Order 7210.38A, April 6, 1984. According to paragraph 10 of the order, "the primary function and responsibility of the CWSU is to provide meteorological advice and consultation to center operations personnel and other designated FAA Air Traffic Facilities, terminal and FSS [Flight Service Stations], within the ARTCC area of responsibility." The information provided by the CWSU is to be developed "through analysis and interpretation of available weather data and is provided in the form of briefings and other weather products (forecasts and nowcasts)."

The CWSUs at ARTCCs are staffed by NWS meteorologists. FAA ATC personnel serving in the position of weather coordinators provide assistance to the meteorologist. The order requires that the meteorologist will conduct "weather familiarization training as required by the [ARTCC] facility manager."

FAA Order 7210.38A states that the weather coordinator functions as the interface between the NWS meteorologist and the facility air traffic staff and "is primarily responsible for the inter/intra facility dissemination of SIGMETS, CWA and urgent PIREPS [Pilot Reports], and provides assistance in the collection and dissemination of other significant weather information."

FAA Order 7210.38A also states that the Weather Coordinator position will be manned on all shifts "and all personnel assigned to this function must have received prior training in the associated duties and responsibilities." The order further states that, weather and workload conditions permitting, the weather coordinator may perform other operational and administrative functions; "however, the primary duty remains that of weather coordinator."

An Assistant Manager for Traffic Management at the Fort Worth ARTCC testified that all facility personnel assigned to the weather coordinator position were qualified to assume the position "through an on-the-job [training] system." He testified that a formal training course at the FAA Academy in Oklahoma City, Oklahoma, had been suspended about 4 years earlier for lack of students due to the 1981 strike. The course had been reestablished in April 1985 and he testified that two of his traffic managers were currently attending it.

The assistant manager further testified that the weather coordinators at the Fort Worth ARTCC are trained to provide liaison between the CWSU and the ATC personnel in the ARTCC and the other facilities within the ARTCC's air space. He further testified that the weather coordinators are neither trained nor qualified to make weather interpretations or to observe the Remote Radar Weather Display System (RRWDS) in the CWSU.

At the Fort Worth ARTCC, the weather coordinator is assigned to the Traffic Management Unit which, in turn, is responsible for administering the national and local traffic management programs that regulate traffic flow within the ARTCC's air space. The weather coordinator works under the Traffic Manager-in-Charge, who is responsible for regulating and surpervising all traffic in the control room.

Paragraph 20 of FAA Order 7210.38A states, in part, that the "total shift staffing and the operational hours of each CWSU shall be specified by the Meteorologist-in-Charge in consonance with the ARTCC facility manager. Shift staffing shall be based upon available manpower, air traffic volume, and weather considerations." NWS meteorologists staff the Fort Worth ARTCC's CWSU between 0600 and 2200. Except for a possible small overlap between the morning and afternoon shifts, only one meteorologist is on duty during the 1400 to 2200 evening shift. On the day of the accident, the meteorologist on duty had reported for his shift at 1400, and the Traffic Manager-in-Charge was also serving as weather coordinator.

The NWS meteorologist on duty at the time of the accident testified that the RRWDS can dial up direct access to five different weather radar sites around the Fort Worth ARTCC's air traffic area, and at the time of the accident Oklahoma City and Stephenville had been selected. The RRWDS is a digitized color display incorporating about a 2-minute delay in its presentation. The RRWDS presents the precipitation in six different colors, and the DFW Airport is located on the display. The RRWDS does not contain height-measuring capability and cannot measure echo intensity at various altitudes as can be done at NWS weather radar sites. As a result, the meteorologist testified that he could interpret the intensity level of a weather cell on the RRWDS, but he could not determine the severity of the weather inside the cell from the return.

The NWS meteorologist testified that on August 2 he took his supper break at 1725. Since the ARTCC's regulations ban food from the radar room, he had to go to the cafeteria, located down a flight of stairs and about 200 feet from the CWSU position. While he could not monitor the weather radar from the cafeteria, he could be paged if he were needed.

The meteorologist testified that there are no normal scheduled times for meal breaks, that all breaks depend upon the existing weather situation, and that, at 1725, he checked the RRWDS before leaving and there were no weather echoes within 10 nmi of the DFW Airport. Although not required to, he notified the assistant traffic manager of his intentions. He testified that he was not paged while in the cafeteria and returned to the CWSU about 1810.

The meteorologist testified that he did not "necessarily" issue a CWA for thunderstorms within 10 nmi of DFW Airport since not all thunderstorms require one to be issued. He testified that only those storms that produce gust fronts and low level wind shears, and that "will have a major impact on [airport] traffic require CWAs to be issued." Paragraph 4.3.3, Attachment 1, FAA Order 7210.38A, states in part that

> the CWA is an unscheduled in-flight flow-control, air traffic, and air crew advisory. It is for the guidance of the ARTCC personnel, air crews in flight, designated FAA facilities, and CWSU meteorologists for use in anticipating and avoiding adverse weather conditions in the en route and terminal environments.

FAA Order 7210.38A further states in part that when "current pilot reports or other weather information sources indicate that an existing or anticipated meteorological phenomenon will adversely affect the safe flow of air traffic within the ARTCC area of responsibility," the CWSU meteorologist "<u>may</u>" issue a CWA. "In this situation the data available must be sufficient, in the judgement of the CWSU meteorologist, to support both the issuance of such an advisory and, if necessary, its continuation."

The CWSU meteorologist testified that he normally did not issue a CWA based solely on the intensity levels portrayed on the RRWDS. He testified that had he seen a VIP level 4 storm in the vicinity of DFW Airport on his radar, he would have tried to ascertain the severity of the cell by soliciting PIREPs and ground truth reports. If he had confirmed that the cell was a thunderstorm, he would have formulated a CWA to be delivered to the weather coordinator for transmission to the tower and Terminal Radar Approach Control (TRACON). He estimated it would take about 5 to 10 minutes between composing the CWA and its delivery to the tower and TRACON.

The CWSU meteorologist testified that if he had seen Cell "D," based on its location and rapidity of growth, he would have issued a CWA. In this instance, he thought he might have sought additional information directly from the TRACON or tower cab.

1.7.4 The Contract Weather Observer

Surface weather observations at DFW Airport are provided by a contract weather service whose observers are certificated by the NWS. The weather station is on the second floor of the Delta Air Lines maintenance hangar on the east side of the airport. The contract weather observer on duty at the time of the accident testified that only 50 percent of the sky, from southeast through north, can be seen from inside the weather station; therefore, he either has to go to the hangar roof or out on the taxiway in front of the hangar to observe the sky from the north through east. After completing the sky condition observation, he has to return to the weather station to take the required instrument readings.

The weather observer transmits surface observations locally to user agencies by electrowriter. The electrowriter reproduces the observer's handwritten weather observations in the offices of all agencies subscribing to this service at the same time they are entered on the electrowriter terminal in the weather office. The weather station also transmits, via the electrowriter, the NWS terminal forcasts and NWS aviation weather warnings received over the teletype.

At 1744, the weather observer testified that he went to the the taxiway to begin his scheduled 1751 observation. He completed his sky observations about 1744, returned to the weather station and took the instrument readings required to complete the observation. At 1751, he transmitted the following observation via the electrowriter:

> 1751 - 6,000 feet scattered, estimated ceiling 21,000 feet broken, visibility 11 miles, temperature 101°F.; dew point 65°F.; wind 120° at 08 knots, altimeter setting 29.92 inches of Hg.; cumulonimbus north-northeast, towering cumulus northeast-south-west-north.

The transmission of the observation was completed at 1752.

The weather observer testified that, while observing the sky conditions for the 1751 observation, he noted a rapidly developing cumulonimbus cloud. After transmitting the 1751 observation, he decided to go back outside to see what was happening to the cloud. He returned to the taxiway and "took a good look at the sky. I noticed a rain shower falling from the CB [cumulonimbus cloud] which was north through northeast of where I was located." While he was looking at the sky, he heard thunder at about 1802. The weather observer estimated that the leading edge of the rain shower was about 3 nmi north of the weather station, but he could not, due to the distance, estimate the intensity of the rainfall. After he heard the thunder, he decided to issue a special surface weather observation, "so once again, I had to note the kind and type of clouds. . . out there, how high they were, the visibility . . . how much, if any, lightning there was, where the rain showers were falling, and so forth." After completing his sky condition observations on the taxiway, the weather observer testified that he ran to the weather station to complete the required instrument readings, and, at 1805, issued the following:

> 1805 - Special, estimated ceiling 6,000 feet broken, 21,000 feet broken, visibility 10 miles, wind 070° at 8 knots, altimeter setting 29.92 inches of Hg., thunderstorm began 1802, north-northeast and overhead moving slowly south, occasional lightning cloud to cloud, rain showers unknown intensity north-northeast, towering cumulus northeast-southeast, west.

The transmission of the observation was completed at 1807.

After transmitting the 1805 special observation, the weather observer returned to the taxiway to observe the weather conditions, and, at 1814, he issued the following:

> 1814 - Special, 400 feet scattered, estimated ceiling 6,000 feet broken, 21,000 feet broken, visibility 11 miles, wind 360° at 37 knots gusting 46 knots, altimeter setting 29.93 inches of Hg., thunderstorm north-northeast and overhead moving slowly south, occasional lightning cloud to cloud, rain showers unknown intensity north-northeast, wind shift 1811.

The transmission was completed at 1816.

The weather observer testified that although not required by reporting procedures, he also called the Fort Worth Forecast Office after he transmitted the 1814 special weather observation to ensure that the forecasters were aware of the change in the wind speed.

1.7.5 Delta Air Lines Meteorological and Dispatch Departments

Delta Air Lines Meteorological and Dispatch Departments are colocated at the Atlanta Hartsfield International Airport, Atlanta, Georgia. The Meteorology Department is staffed by 14 meteorologists and 1 manager. The forecast positions, which are manned 7 days a week, 24 hours a day, include: surface, upper air-wind/temperature updates, and upper air-turbulence.

The meteorologist working the surface position issues three daily terminal forecasts for about 85 stations plus amendments as necessary. He is to brief dispatchers at shift changes and at other times as necessary. He can also provide weather updates via the company's radio to en route flightcrews.

On August 2, 1985, the surface meteorologist on duty between 1430 to 2230 did not provide to either the dispatcher or the flightcrew any information on the weather cell that flight 191 penetrated on its final approach. The meteorologist stated that isolated heavy thunderstorms had developed, as forecasted, northeast of the DFW Airport and were noted on the NWS Radar Summary Charts. He also stated, "At the time of the accident I would have placed these cells still some distance northeast of DFW [Airport]. I was surprised when it became obvious the accident was thunderstorm related."

Federal Aviation Regulation 14 CFR 121.601(c) requires, in part, that dispatchers provide the pilot-in-command during a flight with "any additional information of meteorological conditions . . . that may affect the safety of the flight." This information includes "adverse weather phenomena such as . . . thunderstorms and low altitude wind shear."

The Delta dispatcher on duty at the time of the accident testified that, at 1745 and 1750, he had tried to call up the Stephenville radar site on his television monitor, but the line was busy both times and he did not try again. The dispatcher did not contact flight 191 at any time after the flight had checked in over New Orleans with its required progress report.

1.7.6 Witness Statements

Ground Witnesses.--Witnesses were in agreement that the storm was located north of DFW Airport at or just before the accident. The southern edge of the storm was just north of State Highway 114 or about 1.5 to 2 miles north of the approach end of runway 17L. The eastern and western edges of the storm were 2 miles east and 1 mile west of the extended centerline of runway 17L.

Witnesses said that the storm was moving southward slowly. Eight witnesses on the highway said that the precipitation from the storm had reached or was just reaching the highway as flight 191 went across it. Those witnesses who had encountered rain that evening described the rainfall as heavy to intense. Witnesses on the highway who saw flight 191 emerge from the rain described it as coming out of a wall or curtain of water.

Fifteen witnesses reported seeing lightning and some witnesses heard thunder, and both were reported to have occurred when the storm was near the airport.

Witnesses who commented on the wind indicated that the wind flow was outward from the storm. One witness reported that several highway traffic signs had been uprooted and blown over. Another witness, about 3 to 4 miles north of the airport, reported that a trailer containing 1,200 pounds of fertilizer was overturned during the passage of the storm.

Another witness, about 4 miles north-northwest of DFW Airport, said he saw a large thunderstorm building just north of the airport. He saw two rain shafts coming from the cloud. The storm was divided into two main areas, and the most intense area was just north of runways 17L and 17R. The intense area produced multiple cloud-to-cloud and cloud-to-ground lightning bolts. About 1755, the witness said that he saw what appeared to be a small funnel cloud hanging out of the storm. The funnel was short, very tight, and had "the appearance of a water spout." The base was very high, about at "the eight thousand foot level," and it was hanging out of the west side of the cloud. According to the witness, the storm began to dissipate about 3 minutes later and the wind suddenly increased to about 50 mph or greater.

Passengers on Flight 191.--The surviving passengers were seated in rows 21 through 46. Survivors, passengers and cabin crew who were interviewed, stated that the airplane entered heavy rain during the descent. Some described the color of the clouds outside the airplane as blue-black or said that it got dark outside the airplane. All of them stated that the airplane encountered turbulence before the impact and one, a flight attendant, said the approach was "really bumpy." The other flight attendant stated that it got "very rough" during the approach, and "we were moving in a lateral direction, being tossed about, up and down, left and right."

Flightcrews Landing at or Departing DFW Airport.--Flight 191 was third to land behind flight 351 (a Boeing 727) and a Learjet 25; American flight 539 (a McDonnell Douglas MD-80) was to land behind flight 191.

The captain of flight 351 testified that he had been directed to execute a missed approach because the airplane landing ahead of him had not been able to clear the runway in time. During his approach to the DFW Airport, the captain said he saw only scattered clouds and one "thunderstorm northeast of the field." He said that his Bendix monochromatic weather radar was set in contour mode and the cell did not contour. He could see the cell from the cockpit and "it looked harmless . . . like showers." The captain testified that after passing the outer marker inbound he did not encounter any rain or turbulence, and he did not see any lightning. After the missed approach, flight 351 was vectored to the downwind leg for runway 17L and sequenced into the traffic flow for another approach. After turning on base leg at 2,500 feet, the flight encountered a wind shear and lost about 20 KIAS traversing the area of the shear.

PIREP criteria are contained in the General Operating and Flight Rules (14 CFR 91) and the Certification and Operations: Domestic, Flag, and Supplemental Air Carrier and Commercial Operators of Large Aircraft (14 CFR Part 121) sections of the Federal Aviation Regulations. Title 14 CFR 91.125 requires the pilot in command of an airplane operated under IFR to maintain a "continuous watch . . . on the appropriate frequency and shall report by radio as soon as possible . . . (b) Any unforecast weather conditions encountered; and (c) Any other information relating to safety of flight."

Title 14 CFR 121.561 states as follows:

(a) Whenever he encounters a meteorological condition or an irregularity in a ground or navigational facility, in flight, the knowledge of which he considers essential to the safety of other flights, the pilot in command shall notify an appropriate ground station as soon as practicable.

(b) The ground radio station that is notified under paragraph (a) of this section shall report this information to the agency directly responsible for operating the facility.

The captain of flight 351 testified that he was familiar with the provisions of 14 CFR 121.561, but he did not report the encounter because he believed that "a wind shear of 20 knots at 2,500 feet at [the] airspeed I was at is negligible and certainly would not interfere with the safety of anyone's flight."

Flight 351 was cleared for its second approach to runway 17L at 1800:38 and landed about 1804. The captain testified that he did not go through any weather cells and that, while on final, the nearest one was about 2 miles east of his aircraft. The captain said that, after departing the outer marker inbound he encountered heavy rain which lasted until he descended through 1,000 feet. He did not encounter any turbulence or wind shear, and he did not see any lightning during the approach.

The captain also testified that the airplane's weather radar was not dependable when "you're close to a buildup or thunderstorm." He said that there was not enough definition and that he believed that you would have to be about "ten miles" from the storm to really look at it well.

The Learjet preceding flight 191 in the landing sequence had a Primus model 400 color weather radar. The pilot stated that he used the radar until he was about 25 nmi from DFW Airport and that "nothing looked bad." He was able to see the cells visually. At the public hearing, he testified that he saw this "little buildup" as he approached the airport, and that "it looked harmless." Although his weather radar was still on, he did not recall looking at his radar as he turned on the final approach course.

About 1803, as the Learjet approached the outer marker, the pilot retarded power to decelerate the airplane from 170 to 153 KIAS, the maximum flap extension speed. At 153 KIAS, with power still retarded, he extended the landing gear and flaps and placed the airplane into its landing configuration. While the flaps and landing gear were extending, the airspeed dropped from 153 to 125 KIAS. Since the airplane's power had been reduced "considerably" to slow it from 170 KIAS, and since he had not added power while the flaps and landing gear were in transit, the pilot testified that he did not perceive the deceleration from 153 to 125 KIAS to be the result of a wind shear encounter.

The pilot testified that since he had encountered "light to moderate turbulence" after passing the outer marker, he decided to maintain 150 KIAS on the approach instead of the computed 125 KIAS approach speed. After passing the marker, the airplane entered heavy rain and he lost all forward visibility. Since he had no forward visibility, he thought that if the airplane did not get out of the rain, he might not be able to land, so he decided to "stay high" and fly above the glideslope.

The pilot testified that when he emerged from the rain and saw the runway, the airplane was "high and hot" and they landed "long" because of the approach. After the Learjet landed, the local controller asked the pilot to clear the runway at the high-speed turnoff; however, because the airplane was going too fast and was passing the turnoff, he could not accommodate the local controller. The controller then asked him to "Expedite down to the [next taxiway]." He said that he cleared the runway at the next taxiway and after clearing the runway he looked north and saw the smoke coming from the Delta crash site. With regard to reporting the weather to the tower, the captain testified that he had nothing to report, "the only thing that we encountered was the heavy rain."

Flight 539 was the next airplane behind flight 191 in the landing sequence. Flight 539 was equipped with a Bendix model RDR-4A color radar which, in the opinion of the captain, was "generally a very effective radar."

The captain testified that flight 539 was about 5 to 6 nmi behind flight 191 when flight 539 turned on the final approach course. He testified that there was a buildup in front of flight 539 and almost directly over the final approach course with heavy showers falling from the buildup's base. The captain testified that he observed the buildup on his radar at or inside the outer marker. The buildup was portrayed in red, and no lead-in green and yellow colors were displayed. (The color radar displays a storm in three colors--green, yellow, and red--on a black screen. Green indicates areas of light to moderate rainfall, yellow indicates areas of heavy rainfall, and red indicates areas of heavy and greater rainfall rates or a precipitation reflectivity level in excess of 40 dBZ. The black screen around the perimeter of the cell indicates areas of no detectable rates of rainfall.)

The captain said that they maintained visual contact with flight 191 until it entered the rain shower beneath the buildup. He estimated that flight 191 was about 800 feet AGL when it entered the rain, and he also saw lightning in the area where he lost sight of flight 191. His first officer stated that a cell "with abundant lightning" was directly off the approach end of runway 17L and he saw flight 191 "penetrate the cell."

Although the captain of flight 539 testified that, based on what he had observed visually and on his radar, he was considering rejecting the approach, he continued inbound on the approach until, at 1806:21, the local controller requested flight 539 to "go around." The captain testified that, on receipt of the request, the first officer, who was flying the airplane, added power, leveled off, and turned right to try to go around the right edge of the buildup. "We took it [the airplane] . . . through the fringe area of the buildup, and were in it for approximately ten seconds or so, and then broke out on the other side." While the airplane was in the fringe area, the captain testified, "we were in moderate to heavy rain, and . . . it lasted for most of the time we were in the cloud."

About the time of the accident, Delta flight 1067 was inbound to DFW Airport from the east with its captain observing the airport weather on its Bendix RDR-4A color weather radar. The captain said that when the airplane was about 140 nmi east of DFW Airport and with the 160 nmi range selected on the radar, he saw some "green specks" displayed on a north-south line over the Dallas/Fort Worth VORTAC located about 1 nmi south of the southern end of runway 17L. As the airplane approached the Blue Ridge VORTAC, the captain decreased the radar's range setting to 80 nmi and the "green specks had become yellow cells with a small amount of red contour."

After leaving Blue Ridge VORTAC, the captain said he decreased the radar's range setting to 40 nmi and the cells "had become mostly red with only a trace of yellow around the fringes." (According to ATC data, at 1805, flight 1067 was 8 nmi southwest of the Blue Ridge VORTAC.)

After leaving Baton intersection (27 nmi northeast of DFW Airport) and while descending from 9,000 feet toward the airport, the captain said that, "the cell over the airport was a solid red contour with no yellow or green around the edges and was 15 nmi in diameter . . . . The other cells in the short north-south line were much smaller than the one over the field, and I considered them to be insignificant." The captain compared the rate of development of the cell to "an atomic bomb explosion filmed in slow motion."

Shortly after leaving Baton intersection, the captain was told by ATC that DFW Airport was closed because of the accident. The captain stated that "due to traffic considerations, I was very close to the cell before I could turn . . . and divert to Oklahoma City. I was able to view the cell . . . on 20 nmi radar range. The cell was solid contour and still building." (Transitional areas or rainfall gradients on the radar display are the distances between the leading edges of each of the colors displayed within the portrayed cell or weather echo. Turbulence usually occurs near cells with cores exceeding 40 dBZ. A narrow transitional area or steep rainfall gradient can indicate the presence of moderate or greater turbulence.)

Pilots on the Ground.--Because of the convective weather impacting the ATC route structure, the Severe Weather Avoidance Plan (SWAP) flow control procedures were in effect and were delaying departures from DFW Airport. Many airplanes were positioned on the ramp accessing runway 17L (see appendix D) and along the taxiways leading to the runway awaiting takeoff clearance. Flightcrews in these airplanes as well as on other airplanes located elsewhere at the airport saw the storm approach.

All crewmembers who saw the storm either at or just before the accident stated that it was north-northeast of the airport with its southern or leading edge about 1 to 5 miles from their positions. All of these personnel saw heavy rain falling from the cell and some described the rainfall as a "curtain" of either rain or water. The first officer of a DC-10 holding just west of the threshold of runway 17L stated that he saw an "opaque curtain of rain illuminated by frequent lightning flashes" before the accident. The first officer also noted that at this time the wind sock adjacent to his airplane's position showed the direction of the wind was from 080°. With regard to lightning, crewmembers on two other airplanes said that they saw lightning in the area of the storm cell before the accident.

The crewmembers observing the storm reported that it was moving toward the airport but that it did not reach their position until after flight 191 had crashed. The estimates of the time interval between the crash and the arrival of the storm at their airplanes varied from 1 or 2 minutes to as long as from 10 or 15 minutes. The last estimate was from a crewmember whose airplane was on the outer taxiway at cross taxiway 21 East (21E).

Two captains reported seeing funnel structures within the rainfall area. The captain of a Boeing 727 holding just short of the threshold of runway 17L testified that his airplane was facing east and that he saw a "rain shower approaching the field from the north." When the shower was about 1 to 3 miles north of his airplane, he stated that he saw a funnel-shaped structure within the rain extending from the base of the cloud to the ground. He compared the structure to a water spout he had seen "off the coast of

Florida." He testified that he saw "one or two lightning strikes, cloud to ground" before he saw the funnel and that the lightning was "kind of to the right of where we saw the tornado."

The Boeing 727 was equipped with a Bendix model RDR-1E monochromatic weather radar. The radar was on, the 80-nmi range was selected, and the antenna had been tilted up to eliminate ground clutter. The captain testified that the shower "was directly to our left, about 90° to us, so we didn't pick up anything there." (The azimuth limits of the radar antenna are 90° either side of the longitudinal centerline of the fuselage of the airplane.)

The captain testified that after trying to locate the shower on his radar, he looked up and saw flight 191 crash and that the rain from the storm reached his airplane shortly thereafter. He testified that his radio was tuned to the tower's local control frequency, that he had "counted 20 aircraft on the outer taxiway," and that airplanes were taking off "one right after the other, so there was quite a bit of congestion on the frequency." He testified that he would not have hesitated to break in and report the hazardous weather he had seen, but he saw flight 191 crash before he was able to assimilate what he had seen and that after seeing the accident, "I no longer had any thought of reporting the tornado."

The other captain who observed a funnel structure had just completed an ILS approach to runway 17L. He crossed the outer marker, 5.1 nmi from the end of runway 17L, at 1800:38; testified that he saw two lightning strikes, one on each side of the airplane, after passing the outer marker. After landing, the captain turned his Boeing 737 off the runway onto taxiway 29, and was instructed by the local controller east to hold short of runway 17R. A transcript of the airplane's CVR showed that, at 1803:32, the first officer asked, "Is that a waterspout out there?" The captain testified that he looked out the first officer's side window, and "for about, . . . two or three seconds, . . . it did look, in fact, [like] a tornado out there. It was essentially two very distinct sheets . . . of water . . . . There was a tubular area between the sheets that I think, in retrospect, was the background sky color, which led me to believe it was a tornado."

At 1804:44, after viewing the funnel-like structure, the captain was cleared to taxi across runway 17R. He testified that he had to divert his attention from the weather to taxi his airplane and he did not inform the local controller of what he had just seen. He also did not report that he had seen lightning on the final approach. He testified that he planned to report what he had seen to the ground controller as soon as he reached the parking ramp and was cleared to transfer to ground control's radio frequency. However, he did not make the report.

The flightcrew of one Boeing 737 did use its weather radar to examine the storm shortly before the accident. The airplane had its Bendix model RDR-4A color weather radar on and was facing north on the outer taxiway at the intersection with cross taxiway 21B. After seeing the storm, the first officer selected the 20-nmi range setting, and used full antenna tilt--from 0° to +15°--to examine the storm. The captain said that the storm cell, based on an earlier visual observation, was the easternmost cell in a "short line" of two to four medium-sized cells oriented along an east-west line. When viewed on the airplane's radar the storm cell was about 4 miles from their position. He said the cell was "3 to 5 miles thick and about 4 miles long." The first officer said that the southern edge of the cell was about 5 miles from their position. "The size of the cell was about that of a silver dollar on the radar screen, the intensity was depicted by complete red, [and] there were no transitional colors at the edge of the cell, just solid red."

1.8 Navigational Aids

Not applicable.

1.9 Communications

There were no known communication difficulties.

1.10 Aerodrome Information

DFW Airport, elevation 603 feet, is located 13 miles northwest of Dallas, Texas, and is served by five runways: 18R/36L, 18L/36R, 13L/31R, 17R/35L, and 17L/35R. (See appendix D.) The runways are served by seven ILS and nondirectional beacon (NDB) instrument approaches.

Runway 17L is 11,388 feet long and 150 feet wide and has a grooved concrete surface. The runway has an approach lighting system with sequenced flashers, runway edge lighting, and centerline lighting, and is served by an ILS instrument approach.

The ILS approach to runway 17L transmits on 109.1 megahertz (Mhz). The localizer course is 173°. The touchdown zone (TDZ) elevation is 562 feet and the minimums for the approach are 200 feet AGL and 1/2 mile visibility. The final approach fix (FAF), Jiffy, has a low-frequency radio compass locator and outer marker radio transmitter (LOM) and is located 5.1 nmi from the runway threshold. The minimum altitude at Jiffy and the decision height (DH) for the approach are 2,300 feet and 762 feet, respectively. (See appendix E.)

On August 2, 1985, shortly after the accident, ILS runway 17L was flight-checked, and the facility operation was found to be satisfactory.

1.10.1 Low Level Wind Shear Alert System

The Low Level Wind Shear Alert System (LLWAS) at the DFW Airport was operational at the time of the accident. The system, which has no recording capability, consists of six 20-foot-high vector-vane type of sensors located strategically throughout the airport property. The northeast, southeast, southwest, west, and northwest sensors are located on the airport perimeter; the centerfield sensor is located about 4,463 feet north of the thresholds of runways 17L and 17R and midway between the two runways. The northeast and northwest sensors were nearest to the storm and are located about 3,000 feet north of the thresholds of runways 17 left and right and 18 left and right, respectively.

The six sensors provide wind direction and speed data to a computer and six display units; two display units are located on the east and west sides of the tower cab and four are in the TRACON. The TRACON units display only centerfield sensor data and are located at the following radar control positions: feeder east low, departure south, arrival 1, and arrival 2.

The top row of windows of the tower cab's display units show the centerfield wind direction, speed, and gust speed. The next five rows display wind information from the five peripheral sensors. When a peripheral sensor's average wind reading for 30 seconds shows a vector difference (direction and speed) of 15 knots or more from that of the centerfield sensor's wind reading, an aural alarm sounds and the digital information from the affected sensor or sensors starts flashing in the appropriate row or rows of the tower displays. The flashing continues for five scans of the system's computer, or about 37.5 seconds; the aural alarm lasts for two scans or 15 seconds. The gust velocity is shown in its appropriate window anytime the instantaneous wind speed retrieved from the centerfield sensor exceeds by more than 9 knots the average wind speed retrieved over the previous 2 minutes. Wind gust information is not shown on the readouts for the peripheral sensors. The digital readouts for the peripheral sensors will not appear in the tower displays unless an alert has occurred. However, a controller can obtain a readout for any of the five peripheral sensors by pressing the appropriate blanking switch on the display unit. The readout will be retained until the controller presses the blanking switch.

The LLWAS has several limitations: winds above the sensors are not detected; winds beyond the peripheral sensors are not detected; updrafts and downdrafts are not detected; and if a shear boundary happens to pass a particular peripheral sensor and the centerfield sensor simultaneously, an alarm will not occur. In addition, the dimensions of some meteorological phenomena--microbursts or macrobursts--may be smaller than the spacing between the sensors and thus may not be detected. However, since the downward flow in macrobursts and microbursts turns horizontally as it approaches the ground, an outward flowing shear boundary is established which eventually affects one of the sensors and places the system in alert. The controllers in the DFW Airport tower cab stated that the LLWAS went into alert either about the time the storm reached the north end of the airport or about 10 to 12 minutes after the accident, and when they checked the display, all sensors were in alarm.

Following the accident, the LLWAS was inspected by FAA maintenance personnel and, on August 3, 1985, the system was recertified. The recertification included all system components except the sensor components which measure wind speed and direction. This equipment was not recertified because the equipment required to calibrate the anemometer portion of the sensor was not available at the DFW Airport. On August 12, 1985, the required equipment was brought to DFW Airport. All six LLWAS sensors were removed one at a time, their wind speed and direction measuring components were checked, recalibrated if required, and then replaced at their designated sites. The five perimeter sensors were found to have been accurate. Although the centerfield sensor's wind direction measuring components were found to have been accurate, the wind speed measuring components were reading 4 knots below the speed of the inserted check wind. The centerfield sensor's vector-vane was removed and replaced and the sensor was returned to service.

The cup type of wind sensor used by the contract weather observer at the airport is located within 30 to 40 feet of the LLWAS centerfield vector-vane type of sensor. The weather observer's sensor records wind speed but not direction, and the recorder graph showed that the winds were below 10 knots until 1750. From 1750 until about 1811, the winds averaged between 10 and 12 knots. Between about 1811 and 1815, the winds increased to 46 knots. Between 1750 and 1811, the wind direction, as reported by the TRACON controllers and the local controller, varied between 60° and 90°.

1.11 Flight Recorders

The airplane was equipped with a Fairchild model A-100 Cockpit Voice Recorder (CVR), serial No. 2911, and a Lockheed Air Service Model 209E Digital Flight Data Recorder (DFDR), serial No 586. The CVR and DFDR were removed from the airplane wreckage and taken to the Safety Board's Washington, D.C., Laboratory where they were examined and read out.

The CVR was undamaged. The tape was removed and copied, a time correlation was made with ATC transmissions, and a transcript containing the last 30 minutes of the flight was prepared (see appendix F). The transcript was complicated because the flightcrew was using the cockpit speakers, and cockpit conversation was partially obliterated by incoming transmissions from ATC and other airplanes. Several transmissions from ATC and other airplanes were not transcribed, but are available in the ATC transcripts.

The DFDR was undamaged and in working order on arrival at the Safety Board's laboratory, and its tape was removed and read out. The examination of the readout disclosed two periods where data were lost due to loss of synchronization (sync loss). The first sync loss occurred 9 seconds before the end of the recording and lasted less than 1 second. The second sync loss occurred 3.45 seconds later and covered a 4-second period where sync was intermittent. Sync was regained for the final 2 seconds of the recorded data. Some of these lost data were retrieved through the use of recovery techniques.

The DFDR tape contained, among other monitored parameters, the following data: indicated airspeed; heading; pitch and roll attitudes; angle of attack; position of the lift and drag devices; pitch, roll, and yaw control inputs; rudder, aileron, elevator, and stabilizer trim positions; vertical and longitudinal acceleration forces (Gs); and VHF radio keying.

The VHF radio keying data were correlated to the times contained on the ATC transcript for communications between flight 191 and the ATC facilities. The times were correlated to establish a real-time reference for the various events contained on the DFDR digital readout. The real-time correlation was used to prepare a graphic display of flight 191's landing approach to runway 17L containing the following selected parameters: indicated airspeed; magnetic heading; m.s.l. altitude; engine pressure ratios (EPR) 19/; control column and control wheel positions; pitch and roll attitude; angle of attack; vertical Gs; and selected CVR comments (see appendix I).

1.12 Wreckage and Impact Information

The airplane touched down initially in a plowed field about 360 feet east of the extended centerline of runway 17L and 6,336 feet north of the runway threshold in a wings-level nose-high attitude and on a heading of about 167° magnetic. The left and right main gear tracks extended about 240 feet beyond the initial touchdown point, and the depth of the left and right main gear tracks was 6 to 8 inches and 5 to 6 inches, respectively. The main gear tracks then disappeared for about 320 feet, reappeared for a short distance, and finally touched down just before the north edge of State Highway 114. The nose gear touched down in the westbound lane of the highway.

The airplane knocked over a highway light standard on the north side of the highway and collided with a westbound automobile about 1,500 feet beyond the initial touchdown point. The automobile, which was destroyed, contained a small section of No. 1 engine inlet cowling, and metal pieces from the automobile were found in the No. 1 engine compressor inlet. Measurement of the distance between the main landing gear tracks showed that the airplane was yawed significantly to the left when it crossed the highway. The first pieces from the airplane--pieces of tire tread--were found just

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19/ Engine Pressure Ratio (EPR) is the turbine discharge total pressure divided by total pressure at the compressor inlet; the higher the EPR, the greater the engine thrust output.

beyond the eastbound lanes of the highway, and two light standards on the southern edge of the westbound lanes were knocked over. The airplane breakup, which began as it traversed the highway, continued as it proceeded along the ground toward the two water tanks located on the airport about 1,700 feet beyond the highway.

A 45-foot by 12-foot crater was located about 700 feet beyond the highway. The 2.5-foot-deep crater contained pieces from the accessory gearbox of the No. 1 engine, and the No. 1 engine came to rest about 845 feet beyond the crater. Other components located along the track between the highway and the water tanks included, among others, portions of the nose landing gear, the left horizontal stabilizer, engine components, and pieces of the wing trailing edge flaps and the leading edge slats.

The airplane grazed the north water tank and then impacted the south water tank--about 3,195 feet beyond initial touchdown--and broke apart. The fuselage, from the nose aft to fuselage station 1365 (FS 1365), was destroyed. Both wing sections outboard of the engine pylons separated during the breakup. The left wing came to rest in two inverted sections about 1,125 feet south of the south water tank. The wing sections and attached sections of the trailing edge flaps and leading edge slats were burned extensively. The outboard section of the right wing came to rest in an inverted position about 775 feet south of the south water tank. The No. 3 engine pylon was attached to the wing and the No. 3 engine was partially attached to the pylon. Both wings left a trail of wing components and burning fuel between the water tank and their final positions.

Portions of the airplane were scattered throughout the area extending from the two water tanks to about 1,200 feet south of the southernmost tank. Examination of the wreckage showed that all of the recovered structural components in the area adjacent to and south of the water tanks were sooted and damaged to varying degrees by postimpact fire and heat. Examination of the wreckage did not disclose any evidence of preimpact separation or failure.

The investigation team found the aft fuselage section containing the rear cabin and the empennage was in an upright position. Passengers and flight attendants reported that this section came to rest on its left side and was rolled to the upright position by wind gusts after the arrival of the rescue personnel. The section was relatively intact and included the No. 2 engine and associated ducting, the right stabilizer and elevator, and the base of the vertical stabilizer and rudder. The upper 12 feet of the vertical stabilizer and rudder had separated as a unit during the impact sequence and was found about 100 feet north of the aft fuselage section.

Examination of the recovered sections of the trailing edge flaps and leading edge slats showed that the flaps were extended to 33° and that all leading edge slats were extended.

The airplane wreckage was examined for evidence of an in-flight lightning strike. Although the disintegration of the airplane after it struck the southern water tank limited the amount of structure available for inspection, 33 separate structural segments ranging from the nose landing gear strut to the empennage were located, identified, and examined. The examination, which included all accessible control surfaces, leading edge slats, and trailing edge flaps, and static discharge wicks, found no evidence to indicate that the airplane had been struck by lightning during the landing approach.

The airplane was damaged so severely by impact and postcrash fire and heat that little meaningful information was obtained by examination of its systems and cockpit.

Powerplants.--The No. 1 engine separated from the airplane south of State Highway 114. Ground scars indicate that the engine tumbled and rolled about 800 feet along the ground before coming to a stop. During the tumbling and rolling, the engine was damaged extensively and shed most attached accessories, the engine reverser components, and other engine components. Examination of the engine's rotating components and various components of the thrust reverser system indicated that, at the time of separation, the engine was capable of producing power and was in the full reverse thrust position. The manufacturer's specifications state that, during landing, the reversers will deploy in 1.95 seconds; 2.1 seconds are required to move the reversers from the deployed position to the stowed position.

The No. 2 engine remained in position in the aft section of the fuselage, but its left side was damaged significantly by impact forces. The engine inlet and fan section, which had been protected by the fuselage structure during the crash, exhibited minor damage from the ingestion of miscellaneous debris, such as airplane seat cushions, seat sections, and other pieces of the airplane's interior furnishings. This debris was found as far back as the high-pressure compressor. Examination of the engine's rotating and thrust reverser components indicated that the engine was capable of producing power at impact and that it was in the full reverse thrust position, but that it had been commanded to the stow or forward thrust position.

The No. 3 engine, which had remained with the right wing during the airplane breakup, was found with its inlet section pointing opposite to the direction of flight. The engine was damaged severely during the impact sequence. Examination of the rotating components of the engine indicated that it was developing power at impact. Examination of the components of the thrust reverser system indicated that the system had been commanded to the stow or forward thrust position, and the thrust-reversing components in the engine were in transit at impact.

1.13 Medical and Pathological Information

The three flightcrew members sustained fatal injuries as a result of the accident. The pathological examinations disclosed no abnormal conditions. Toxicological analysis of the flightcrew was limited by the availability of suitable specimens and the following results were the only ones possible to obtain. These results were reported by the FAA's Civil Aeromedical Institute (CAMI): Ethyl alcohol was not detected in either the captain or first officer. Carbon monoxide was not detected in the first officer.

1.14 Fire

Passengers saw fire enter the left side of the mid-cabin area after the airplane struck the automobile and before its left side struck the water tanks. The right exterior surface of the separated rear cabin section containing the majority of the survivors was sooted heavily, but the interior of the cabin was not damaged by heat. Parts of the airplane forward of the separated rear cabin section were subjected to severe postimpact and ground fire.

1.15 Survival Aspects

The airplane's passenger cabin contained 46 rows of seats and a total of 302 seats. (See figure 3.) There were 152 passengers on board flight 191: 71 adult males; 62 adult females; 18 children (24 months or older, but younger than 16 years); and one infant (younger than 24 months). The ages of the passengers ranged from 20 months to 70 years. In addition, 11 crewmembers were aboard.

The fuselage forward of FS 1365--forward of seat row 34--including the cockpit disintegrated after the airplane struck the water tanks. However, the passengers said fire entered the cabin through the mid-cabin left wall before the airplane struck the water tanks, and they tried to shield themselves from the flames as the fire propagated into the cabin. The forward cabin containing the cockpit and first 12 rows of passenger seats was destroyed on impact with the water tanks, and there were no survivors from this part of the airplane.

The mid-cabin section was also destroyed. Some of passengers seated in this section, some still in their seats, were ejected onto the ground. Of the 60 passengers seated in this section, 52 were killed. All 8 survivors suffered blunt force trauma; 7 of the 8 survivors sustained thermal injuries in addition to blunt force trauma. One of these 8 passengers had been seated in row 21, the remaining 7 were seated between rows 27 and 33.

The rear fuselage separated from the airplane between seat rows 33 and 34 and the separated rear cabin section contained 33 passengers and 4 flight attendants. Of these 37 persons, 17, including 1 flight attendant, died. Of the 20 survivors, 18 received injuries ranging from serious to minor, and 2 received no injuries. None of these survivors sustained thermal injuries.

There was massive disruption of cabin floor, walls, and ceiling of the separated rear cabin section beginning at the point of separation and extending rearward to just forward of row 40. Fifteen persons, including 2 flight attendants, were seated in this part of the cabin: 10 passengers and 1 flight attendant were killed, 3 passengers were injured seriously, and 1 flight attendant had minor injuries.

Except for the left cabin wall, which was missing, the remainder of the separated rear cabin section from row 40 aft to row 46 was relatively undamaged. Six passengers seated along the missing left cabin wall were killed. The remaining 16 occupants of this cabin section, including 2 flight attendants, sustained serious and minor injuries, and 2 passengers were not injured.

The rear cabin section came to rest on its left side. The survivors were either flung from the airplane in their seats or released themselves from their seats and exited at the forward end of the separated fuselage section or through the missing left wall. One flight attendant and three passengers could not escape from the cabin because of injuries and were removed by fellow passengers and rescue personnel. Two other flight attendants had only minor injuries and were able to escape unaided after shouting commands to the passengers to get out of the cabin. The flight attendant seated at the right rear (R-4) exit had difficulty releasing her seatbelt because the buckle was located on her left hip and her weight was on the buckle. The passengers and flight attendants were covered with fuel and some had fuel on their hands and in their eyes, which caused difficulties in climbing down the cabin to the hole created by the missing left cabin wall. Some persons were able to climb downward to the hole over seats while others fell the width of the cabin to the ground.

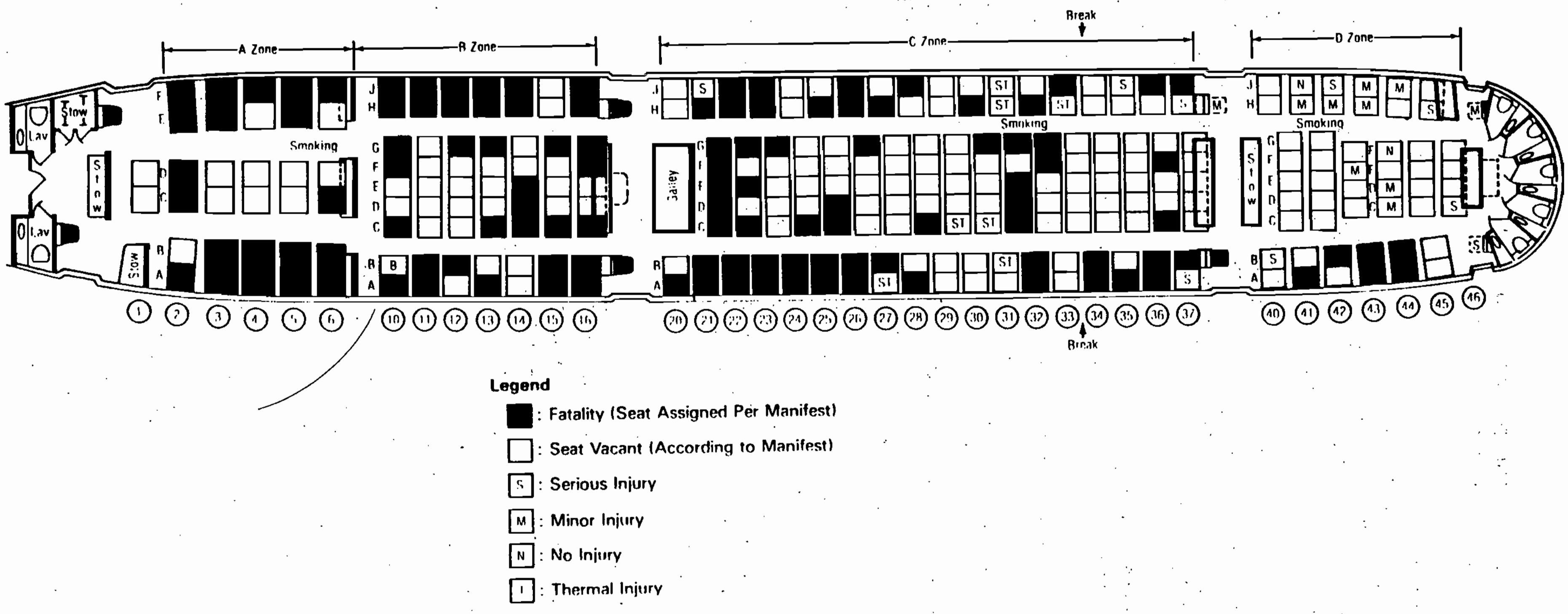

Figure 3.--L-1011 cabin seat diagram.

Shortly after most of the passengers and flight attendants had exited, high winds blew the rear cabin upright and rescue personnel removed two passengers.

1.15.1 Emergency Response

Three fire stations are located on DFW Airport. Fire station No. 1 was about 2 miles south of the accident site; station No. 2 was about 3 miles west of the site; and station No. 3 was about 0.5 mile southeast of the site. At 1806, the DFW Airport's Department of Public Safety (DPS) Communications Center in the airport's Fire Station No. 1 was notified of the accident and its location. The communications center immediately alerted all fire and emergency units. Fire trucks responded from the three airport fire stations, and additional firefighting and police personnel responded from various locations around DFW Airport.

Within 45 seconds after notification, three airport fire trucks from fire station No. 3 were at the accident scene, three more fire trucks from fire station No. 1 arrived within 4 minutes, and two more from fire station No. 2 arrived within 5 minutes after notification. The fire trucks had 15,100 gallons of water, 1,695 gallons of aqueous film-forming foam, and 3,000 pounds of dry chemical agents. Twenty-six DPS personnel, including 16 Emergency Medical Technicians (EMT) and 2 paramedics, were also at the scene. Despite heavy rains, high winds, and wind gusts from varying directions which hampered the application of fire extinguishants, most of the fires were either put out or under control within about 10 minutes after notification. As fires came under control, the firefighters assisted in rescuing trapped and injured persons.

The airport's DPS Mobile Intensive Care Unit and Medical Patrol Vehicles arrived at the scene about 4 minutes after notification, or about 1810. Triage stations were established and triage procedures were implemented. Typical aid given to victims at the site was treatment for shock, dressing of traumatic injuries including burns, and many actions to stop profuse bleeding. The EMTs estimated that without the on-scene triage procedures and treatment, at least 50 percent of the surviving passengers would have died.

At 1814, the DPS Communications Center operator, using a mutual aid agency notification checklist, began to notify off-airport police, fire, and ambulance agencies to request assistance as prescribed in the FAA-approved DFW Airport Emergency Plan. The checklist required the operator to make 21 telephone calls (many with alternate numbers), 2 radio notifications, and 2 off-airport alert broadcasts, while simultaneously monitoring the airport's primary police radio channel. The operator did not complete the checklist until 45 minutes after the accident.

Parkland Hospital in Dallas, about 12 miles from the airport, was advised initially of the accident at 1819 by the airport's paramedic unit and at 1831 by the DPS operator. By the time the trauma team from Parkland Hospital arrived, about 35 to 40 minutes after the accident, the majority of the injured had been transported to nearby hospitals.

At 1828, the DPS operator notified the John Peter Smith Hospital in Fort Worth; however, the Hurst-Euless-Bedford and Northeast Community Hospitals, which are closer to DFW Airport, were not notified although both received injured persons from the crash. None of the hospitals received notification on victim status or intended destinations.

The adjacent communities of Irving, Grapevine, and Hurst did not receive specific requests for ambulances; however, the ambulance company in Hurst overhead the DFW Airport's radio crash alert and responded quickly after confirming the accident with the airport by telephone. Ambulances were not requested from Grapevine until after the Grapevine fire chief met with the airport's fire chief at the accident site at 1840. The city of Irving did not receive a request for ambulances although the fire chief did dispatch an Emergency Medical Service (EMS) unit to the airport to ask if ambulance assistance was needed.

Although the DFW Airport Emergency Plan contained procedures for requesting mutual aid ambulances, off-airport agencies did not clearly understand what assistance was being requested. In some cases, only fire units were dispatched when ambulances were also expected.

The DFW Airport Emergency Plan met the requirements of 14 CFR 139.55. The last FAA certification inspection of the airport and the emergency plan was completed November 14-15, 1984, and the last disaster drill was conducted by the airport in May 1979.

1.16 Tests and Research

1.16.1 Wind Shear Research

Wind shear has long been identified as a flight hazard and one that can be extremely dangerous during takeoff and landing operations. According to FAA Advisory Circular (AC) 00-50A, "Wind shear is best described as a change in wind direction and/or speed in a very short distance in the atmosphere. Under certain conditions, the atmosphere is capable of producing some dramatic shears very close to the ground. . . ." One of the atmospheric conditions capable of producing "dramatic shears" is the downburst from convective or cumuliform clouds. (See appendix G.)

A downburst 20/ is a strong downdraft which induces an outburst of highly divergent damaging winds on or near the ground. Downbursts vary from less than 1 kilometer (0.62 mile) to tens of kilometers in diameter. Downbursts are subdivided into macrobursts and microbursts according to their horizontal scale of damaging winds. A macroburst's horizontal wind field extends in excess of 4 kilometers (2.5 miles) in diameter, whereas the microburst's horizontal wind field extends less than 4 kilometers (2.5 miles) in diameter. (See figure 4.)

The hazards to flight inherent in downbursts were demonstrated on July 9, 1982, at Kenner, Louisiana, when a Pan American World Airways Boeing 727 crashed after encountering a microburst shortly after takeoff. One hundred and forty-five passengers and 8 persons on the ground were killed in the accident. The Safety Board determined that the probable cause of the accident

> was the airplane's encounter during the liftoff and initial climb phase of flight with a microbust-induced wind shear which imposed a downdraft and decreasing headwind, the effects of which the pilot would have had difficulty recognizing and reacting to in time for the airplane's descent to be arrested before its impact with trees. 21/

20/ Fujita, T. Theodore (1985): The Downburst - Microburst and Macroburst.
21/ Aircraft Accident Report--"Pan American World Airways, Inc., Clipper 759, Boeing 727-235, N4737, New Orleans International Airport, Kenner, Louisiana, July 9, 1982" (NTSB/AAR-83/02).

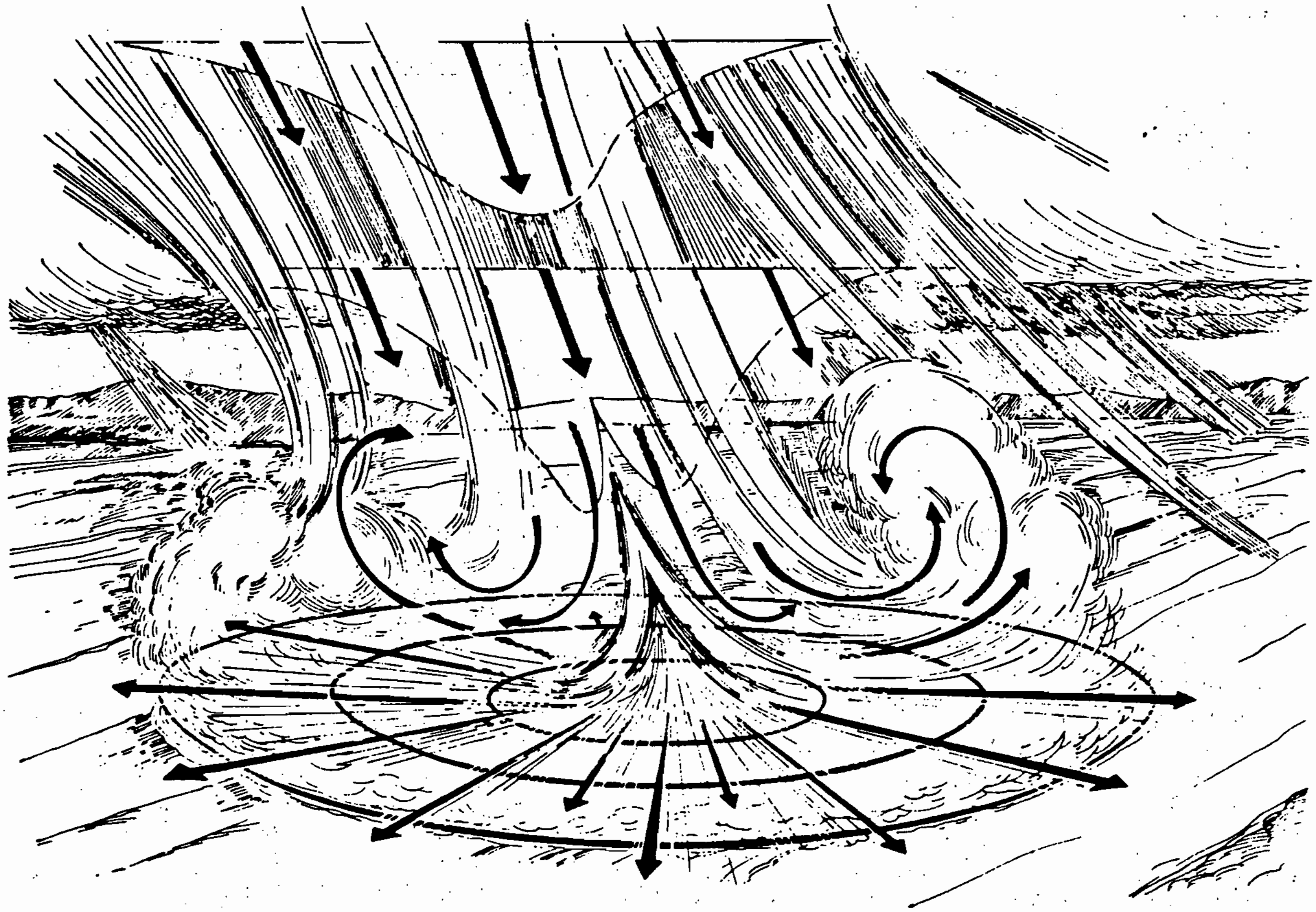

Figure 4.--Typical microburst wind field.

Much of the recent investigation of the downburst phenomenon has been concentrated geographically around Stapleton International Airport, Denver, Colorado, during two research projects: the Joint Airport Weather Study (JAWS), which ended August 13, 1982, and the Classify, Locate, and Avoid Wind Shear (CLAWS) Project which began July 2, 1984, and ended August 15, 1984.

The director of the JAWS and CLAWS programs testified that the distance across a microbust can be as little as 3,000 feet, or as great as 10,000 feet. An airplane traversing a microburst initially encounters the outflow on the front side, which increases the headwind component, causing the airplane to rise and its indicated airspeed to increase. Several seconds later, the headwind component begins decreasing and the airplane traverses the central core downdraft, "which can be very strong." Finally, the airplane encounters the back side of the microburst, and the tailwind component begins to increase, causing the airplane to sink and its indicated airspeed to decrease. "The time across this whole feature is anywhere from 20 to 40 seconds. That's not very long and can create serious performance problems for an airplane. . . ." Assuming that the microburst's horizontal outflow winds are 30 knots, then during the 20 to 40 seconds required to traverse the area, an airplane would encounter a 60-knot horizontal wind shear.

The project director testified that during JAWS, "We found that for about 75 microbursts, the average [wind speed spread] across it was 47 knots. . . The average microburst for an airplane is very severe. The wind differential across the . . . microburst [encountered by the Pan Am flight at Kenner] was about 47 knots." He also testified "half the ones we looked at were stronger than [47 knots]." During JAWS, researchers had measured microburst wind differences in the 65-knot range, and "found one up here in the almost [one] hundred-knot range."

The project director testified that the LLWAS system "does a good job with gust fronts. We found in an analysis of our work in Denver in 1982 that it did not do a particularly good job with microbursts." The director cited the following reasons for this: a microburst tends to be smaller than the distance between sensors. the LLWAS is like a net, but the mesh is too coarse, and microbursts slip through. A lot of microburst action took place outside of the sensor locations, and "some sensors are sheltered, trees have grown up around them and they do an inadequate job detecting the wind." The project director concluded that the LLWAS is "a limited system but it can be improved and must be improved. It's the only system we've got right now, and let's make the most of it."

The CLAWS project was implemented by the FAA after a microburst wind shear takeoff mishap at Stapleton Airport. Immediately following the mishap, the FAA contacted the National Center for Atmospheric Reseach (NCAR) in Boulder, Colorado, and asked if they would use Doppler radar to protect Stapleton Airport. Although the NCAR microwave pulse Doppler radar was located about 18 miles northwest of the airport, they tried to protect or cover a 5 nmi radius around Stapleton Airport with pulse Doppler radar. (Doppler radar can, in addition to detecting precipitation, measure the velocity of the scatter echo of precipitation and other aspects of the atmosphere; it measures any component of motion perpendicular to the direction of its antenna and, therefore, can measure the speed of the winds within a weather cell.) During the CLAWS project, meteorologists were on duty in the radar room and in the tower cab, and were passing information directly to ATC and "hence, to pilots." The meteorologists used the Doppler radar to locate the microburst, estimate the differential shear across its diameter, provide a warning to the controller, which the controller would read to the pilot. (For example, weather radar indicates a microburst 2 miles north of Stapleton. Wind shear may be 55 knots). The project director testified that they issued 30 microburst advisories in 45 days to 30 pilots; 7 pilots rejected the approach and executed a go-around.

In addition to the nowcasts based on the Doppler radar information, the project also issued a daily forecast of microburst probability. The forecast was based on analysis of the dry adiabatic lapse rates 22/ and the presence of moisture aloft in the atmosphere. The project director testified that the forecast was 80 percent accurate in determining that a microburst would occur near Denver that day. The forecast was delivered to the weather service and was distributed nationally every morning the forecast was made. The project director testified that, although they cannot pinpoint 12 hours in advance where a microburst will be, they can identify the days "where a microburst is likely to occur for the dry high (cloud)-base type cases." He then testified that "we do not yet know how to forecast the conditions for a microburst in the heavy wet Southeast or humid regions of the United States."

A NOAA research scientist testified that the microburst problem is far from being solved. He testified that not all thunderstorms produce significant outflow winds nor do they produce microbursts. In addition, the potential for a microburst cannot be predicted based on the intensity of the weather echo. Since present-day NWS radar can only measure the intensity of the precipitation contained in the cell, he testified that he did not know of any technique available to the NWS radar specialist that would allow him to determine which convective echo on his radar would produce a microburst. He testified that the Doppler radar is the best available sensor to detect the presence of a microburst. The JAWS and CLAWS project director testified that "we found out . . . microbursts were enormously detectable with Doppler radar."

The research scientist testified that the research data showed that microbursts develop so rapidly and the responses are so transient that two airplanes, one following another through the microburst see entirely different things. He also testified that the JAWS data showed that, in general, "the microburst as seen by Doppler radar has a lifetime on the order of five minutes or longer, but not over ten minutes."

In addition, the research scientist and the JAWS director testified that the research data also indicate that the descending column of air in the microburst may produce horizontal vortices along its boundary with the environmental air.

The testimony at the Safety Board's public hearing disclosed that past and present microburst research has had very little impact on NWS operations and that formal training concerning research results had not been implemented.

NOAA has been involved in developing microburst forecasting techniques based on JAWS data for about 4 years. Although these techniques show great promise, for the most part this information and formal training to use these techniques have not been provided to operational meteorologists. The Safety Board believes that every effort must be made to ensure that pertinent information developed from microburst research is provided to operational meteorologists, and that formal training programs based on this information be implemented as soon as possible.

1.16.2 Wind Field Analysis

The microburst phenomena is often a part of the evaporation-condensation process which produces cumulonimbus clouds, heavy rainshowers, and thunderstorms. The wind shear results from the convective movement of the air wherein low-level air heated

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22/ The rate at which unsaturated air moving upward or downward cools or warms. The rate is independent of the temperature of the mass of air through which the vertical movements occur.

by the ground rises and is replaced by cold air descending from aloft. The low-level wind condition is analagous to pointing a high-pressure air hose at the ground; the vertically descending air fans out in all directions.

When a microburst is encountered during a landing approach, the airplane will typically experience an increasing headwind, a downdraft, and a decreasing headwind in rapid succession as it passes beneath the outflow and descending air column. The increasing headwind will be recognized as the indicated airspeed increases suddenly and the airplane tends to rise above the glidepath. However, this apparent increase in airplane performance is shortlived as the airplane enters the downdraft and encounters the decreasing headwind caused by the reversal in the direction of the outflow. The rapid reversal of wind direction and speed produces sudden changes in the airplane's angle of attack and airspeed, which may reduce the airspeed far below the initial stabilized airspeed. The reduced airspeed will result in reduced vertical lift, causing the airplane to accelerate downward. Furthermore, the airplane's longitudinal stability will cause the airplane to pitch nose downward as it attempts to reacquire its trim speed equilibrium. The extent to which the airplane's flight path changes depends upon the severity of the wind shear and the pilot's reaction with flight controls and engine thrust. The microburst might also create horizontal vortices which produces sudden changes of vertical wind speeds to further upset the longitudinal stability and perhaps the lateral and vertical stability of the airplane, exacerbating the pilot's control task.

At the Safety Board's request, the Lockheed California Company and the National Aeronautics and Space Administration (NASA) analyzed the information from flight 191's DFDR to determine the horizontal and vertical wind velocities affecting the airplane's performance during the instrument approach to the DFW Airport. The computations performed during this analysis were based on the following general assumptions:

- the weight and configuration of the airplane at the start of the ILS approach;
- the weather conditions at the DFW Airport at the time of the accident; and
- engine and airplane performance parameters derived from Rolls Royce and Lockheed documentation.

In determining the wind field penetrated by flight 191 during the approach to DFW Airport, the airplane's inertial flightpath was reconstructed based on data retrieved from the airplane's three accelerometers. The inertial flightpath was then compared with flightpaths constructed from radar data retrieved from the Fort Worth ARTCC's National Track Analysis Program (NTAP). The inertial flightpath overlay showed good correlation with the NTAP flightpath and the transponder altitude readout.

The three-dimensional, along-track wind field transited by flight 191 was reconstructed by comparing an inertially reconstructed flightpath to the air data information provided by the DFDR.

The "along flightpath winds" developed by NASA and Lockheed correlated reasonably well. Both analyses revealed that flight 191 penetrated a divergent wind field whose pattern resembled a microburst wind field pattern. Flight 191 encountered an initial increasing headwind, followed by a downdraft and a series of updrafts and downdrafts, in the presence of an increasing tailwind (decreasing headwind).

The general pattern shown in the analyses indicates that flight 191 encountered a strong downflow for a period of 20 seconds, followed by a series of rapid changes in vertical wind direction spaced about 5 seconds apart. In the period of the major downflow, the airplane experienced downdrafts from about 6 knots to about 24 knots. As the airplane entered the downflow, the headwind increased from about 10 knots to a maximum of 27 knots. Then, during a period of 26 seconds, there was a change to a 40-knot tailwind. Based on the rotation of the horizontal wind direction, the source of the downflow appeared to have been to the west of the flightpath.

A control column force analysis performed by Lockheed showed that a 22-pound push force was applied to the control column about 12 seconds before initial touchdown. Over the next 4 seconds, the forces were reversed, and by 8 seconds before impact, a 25-pound pull force was being exerted. Over the next 7 seconds, the forces again reversed and by 1 second before impact a 10-pound push force was being applied. During the last second the push force was decreasing.

At the Safety Board's public hearing, a NASA Aerospace Engineer amplified the manner in which the wind analysis was performed. He testified that both Lockheed and NASA used a similar analysis approach and that the results of the two analyses were "generally . . . the same."

The aerospace engineer testified that NASA also used the DFDR data to determine whether there had been any degradation of airplane performance due to heavy rain. When the lift generated by the airplane was compared with lift performance based on good airplane test data, no significant differences were identified between the predicted lift and the measured lift. He testified, "In terms of lift, there does not seem to be any performance degradation." He also testified that, because their work on drag performance had not been completed, they could not talk about drag with the same degree of confidence. However, he said that "we do not see any drag values out of order relative to what we'd expect. At the moment, we see no performance degradation." Later analysis of the airplane's drag performance substantiated this conclusion.

With regard to the rainfall rate encountered by flight 191, data showed that the maximum convective rate associated with a VIP level 4 echo (intensity = 49 dBZ) is about 3.7 inches/hour. A rain gauge located just west of the initial impact point had collected about 0.9 inch of rain in a 15-minute period, a rate of 3.6 inches/hour. Just before 1810, the RVR (runway visibility range) on the touchdown end of runway 17L had decreased to 1,600 feet. Calculations of rainfall rates based on RVR values 23/ indicate that a 1,600-foot RVR corresponds to a rainfall rate of 12.6 inches/hour. The evidence indicates that the rainfall encountered by flight 191 probably fell at the rate of at least 4 inches/hour.

NASA also evaluated how the use of different pitch attitude histories would have altered the airplane's flightpath through the wind shear. The evaluation had two objectives: first, to determine if the derived wind field exceeded the airplane performance limits; and second, to test the wind shear recovery technique requiring the pilot to rotate the airplane to a target pitch attitude, hold that attitude unless persistent activation of the stall warning stickshaker occurs, then reduce the pitch attitude enough to end the stickshaker activation.

23/ Dietenberger, M.A., Haines, P.A, and Luers, J. K., "Reconstruction of Pan Am New Orleans Accident." Journal of Aircraft, Vol. 22, No. 8, August 1985.

The aerospace engineer testified that this was "in large part, an academic exercise, because . . . if the newly generated flightpath was a significant distance from the path on which flight 191's flightpath winds were measured, then our assumption regarding the use of flight 191's winds, "becomes less and less valid." He testified that if a flightpath quite close to that of flight 191's is assumed, then the assumption of the same winds to produce the new flightpath is "reasonably valid." Therefore, a series of pitch attitudes ranging from 15° to 2° nose-up were examined.

The lowest alternate path examined during this exercise cleared the ground by 100 feet. This path was generated by allowing the airplane to pitch down as it did 14 seconds before impact but arresting the downward pitch at 2° nose-up, maintaining that attitude, "and then pulling up at a very modest rate toward the end of the period." The 15° nose-up pitch attitude produced a flightpath well above that of flight 191; however, the aerospace engineer testified that the assumption of the same winds for that flightpath was "very sketchy."

According to the engineer, the 2° nose-up flightpath "did not result in any increase of any peak angles of attack . . . . and it resulted in only a few knots change in the airspeed." He testified that, based on the fact that the lowest alternate flightpath cleared the ground, "we could deduce . . . the airplane physically had the performance capability to fly a path that missed the ground." The facts show that the airplane initially touched down "with a very modest descent rate. It came very close to missing the ground, and it takes a . . . very small path differential . . . to start . . a slight climbing path at that particular point [initial touchdown]." Because of the loss of DFDR data after the initial touchdown, the aerospace engineer testified that, "Beyond [the point of initial touchdown] with no record and no information we can't deduce what would go on after that. There might be a terrific tailwind at that point, or a terrific headwind. You can only work with what you've got."

The aerospace engineer also testified that the DFDR information indicated that the flight was experiencing "unusually heavy turbulence" during the last portion of the descent. At one point, about 15 seconds before initial impact, the airplane rolled 20° right and the control wheel was deflected full left to recover, which, "strongly suggests flight through (or) pretty close to the center of a vortex flow."

The NASA computations showed three angle-of-attack peaks during the last 15 seconds of the flight. The first peak occurred about 15 seconds before initial impact and had a "brief spike" slightly above 21°. Since Lockheed data show that the stall warning stickshaker will activate at an angle of attack of 19° plus or minus 1/2°, the aerospace engineer testified that the 21° spike:

> would provide a one-second interval of stickshaker.
>
> The second peak (9 seconds before impact) . . . gets to about a 15° angle of attack which is . . . three or four degrees below stickshaker, I wouldn't expect a stickshaker there.
>
> The third peak during the final pull-out (5 seconds before impact), is about 18 1/2. Giving allowance for slight errors, tolerances in the angle of attack device, there might have been a very brief excitation of (the stickshaker) . . . less than half a second.

1.16.3 Airplane Performance

Because the recorded information from the DFDR contained, in addition to airplane performance data, the control inputs made by the pilot, the Safety Board was able to determine and analyze the pilot's response to the derived winds.

The performance data indicated that the flight proceeded uneventfully until the final 47 seconds of the flight. The airplane was descending through about 800 feet AGL, on the ILS glideslope, at 150 KIAS (Vref + 13 KIAS), and holding a nose-up 4.5° pitch attitude.

Between 1805:05 and 1805:19, the airplane encountered an increasing headwind component. The onset of the increase was gradual, but between about 1805:12 and 1805:19, the headwind component increased at a rate of about 2.7 knots/second. During this 14-second period, the airplane accelerated to about 173 KIAS, and the first officer retarded the throttles. By 1805:15, despite the instructions in the Delta L-1011 Pilot Operating Manual (POM), which states, "do not unspool the engines," all three engines were either at, or very near, flight idle EPR and remained at that thrust level until 1805:22. During the first part of this period, the first officer also applied a gradual nose-down control input. By 1805:14, the pitch attitude reached 1.3° nose-up and then began to increase as the first officer began to apply nose-up control inputs. At or shortly before 1805:19, the airplane encountered a strong downdraft. The vertical winds changed from a 10-fps updraft to a 20-fps downdraft. The first officer's response was to apply further nose-up control input and the pitch attitude increased to about 7° nose-up. At 1805:19, the captain warned the first officer, "watch your speed," and 1 second later the airplane entered the heavy rain.

From 1805:19 to 1805:29, the headwind decreased by about 25 knots and the downdraft increased from about 18 fps to more than 30 fps. Thrust was near flight idle during the first 6 seconds of this period and, combined with the loss in headwind component, resulted in a loss of about 30 knots of airspeed. During the last 4 seconds of this period, thrust was increased to within 0.01 to 0.02 of go-around power. (Delta's procedures require the flightcrew to ascertain the go-around or missed approach EPR during the approach check and to set the indicator or EPR bug on each EPR indicator to the computed setting. The CVR transcript showed that this checklist item was completed at 1757:13. The go-around EPR for this approach was 1.48 EPR. Assuming that the throttles were pushed full forward to their stops, the maximum available EPR would have been about 1.53 EPR.) Even as thrust was being applied, airspeed continued decreasing to about 129 knots, for a total loss of 44 knots in 10 seconds. Also, pitch attitude was increased to about 15.7° nose-up to maintain glideslope and counter the strong downdraft. At 18:05:29, the decreasing trend of the headwind again reversed itself, and along with a high thrust condition, resulted in a rapid increase in airspeed from about 129 to 147 KIAS. At 18:05:31, thrust was reduced from an engine pressure ratio of 1.47 to 1.33 and by 1805:35 the airspeed decreased to 140 KIAS. The DFDR data showed that between 1805:19 and 18:05:35, flight 191 had essentially maintained the glideslope despite airspeed fluctuations of +20 knots to -44 knots and downdrafts from 15 to 40 fps during the preceding 32 seconds.

At 1805:35, flight 191 encountered an atmospheric disturbance which could best be described as severe and localized. Within 1 second, large variations in wind components along all three axes of the aircraft were noted. Indicated airspeed decreased from 140 to 120 knots, the vertical wind reversed from a 40-fps downdraft to a 20-fps updraft, and a severe lateral gust struck the airplane as well. This gust resulted in a very rapid roll by the airplane to the right, requiring almost full lateral flight control authority to level the wings. Of equal importance was that the airplane's angle of attack increased from 6° to approximately 23° degrees, and most likely increased more rapidly, and to a higher value, than recorded by the DFDR because of the rate-limited angle of attack sensors. Although the sound of the stickshaker was not heard on the CVR, the stickshaker probably activated, albeit for only about 1 second. This severe environment that flight 191 encountered most likely is what prompted the captain to say, "Hang onto the (non-pertinent word.)" It was also about this time that engine thrust was applied.

The DFDR data showed that the power began increasing on the engines at about 1805:36. By 1805:44, all three engines had reached about 1.53 EPR and they remained at that thrust level until the airplane touched down the first time.

During the next 3 seconds, in response to the pitching moments induced by the much higher-than-trim angle of attack and the pilot's nose-down control column deflection, a rapid nose-down pitch rate developed. By 1805:39, the airplane's pitch attitude was 3.6° nose-up, and continuing downward. Also at this time, the vertical wind reversed again from an updraft to a strong downdraft. Between 1805:35 and 1805:48, the derived wind calculations showed six strong reversals in the vertical wind component. The strong downdraft, combined with the airplane's rapid nose-down pitch rate, induced a sudden reduction in angle of attack to near zero. In fact, a vertical acceleration of +0.3 g was recorded by the DFDR. As a result, the airplane began a rapid departure from the glideslope.

At 1805:40, the DFDR data indicated a large forward-from-trim deflection of the control column. The resultant pitching moment was sufficient to overcome the nose-up moment resulting from the low angle of attack prior to 1805:42, and the nose-down pitching rate began to increase. At 1805:42, the vertical wind reversed again, resulting in an angle of attack increase from 5° to 14° degrees in approximately 1 second. This combination of nose-down, pilot-induced control column force and the above-trim angle of attack resulted in a peak nose-down pitching acceleration at 1805:43. Both of these pitching moment contributions reversed after 1805:44, but not before inducing a nose-down pitch rate of about 5° per second as the pitch attitude decreased through 5° nose-down.

Beginning at about 1805:40, a large increase in the tailwind component was recorded. Due to the 30-knot tailwind, airspeed did not increase beyond about 135 knots despite maximum thrust and a steepening flightpath. By 1805:44, the airplane was at 420 feet AGL, its descent rate was about 3,000 feet per minute, its airspeed began to increase, and it was in a strong downdraft. At 1805:44, the CVR recorded the first GPWS alert, and 1 second later, the captain called "TOGA." The low angle of attack resulting from the low pitch attitude (7.4° nose-down), and the strong downdraft combined with a substantial nose-up control deflection, produced a large nose-up pitching moment. This reversed the pitch attitude trend, but not until pitch reached about 8.3° nose-down.

At 1805:46, with the airplane at about 280 feet AGL, its descent rate was close to 5,000 feet per minute. By 1805:48, the vertical wind changed from about 40-fps downdraft to about 10-fps updraft. This reversal in wind component, combined with a substantial nose-up pitch rate, increased angle of attack rapidly. At 1805:48, a +2.0 g vertical acceleration was recorded. It is probable that, for about 1 second, the stickshaker activated for the second time, and pitch attitude peaked at 6° nose-up. At 1805:50, another downward trend in pitch is noted, so that, about 2 seconds before initial ground contact, a pitch attitude of about zero degrees was recorded. In the last second before ground contact, pitch increased to approximately 3.1° nose-up.

From 1805:45, until initial ground contact at 1805:52, no further longitudinal wind changes were noted. Accordingly, the airplane's airspeed increased steadily to about 170 KIAS at touchdown.

Some DFDR data were lost in the 4 seconds subsequent to initial touchdown. It is estimated that the vertical descent rate at touchdown was on the order of 10 fps, certainly not enough to compromise the airplane's structural integrity. A nose-down control deflection and a reduction in engine power were also observed during this 4-second period.

1.16.4 Flight Director System Study

The Safety Board requested the Lockheed and Collins Companies to analyze the pitch commands that would have been displayed by the flight director system's pitch command bar during the descent. The completed analysis depicts the last 52 seconds of the flight before initial ground contact.

The simulation of the final seconds of the flight begins with the airplane on the glideslope, 1,045 feet AGL, and 52 seconds from initial impact time. The simulation was operated in a three-DOF (degree of freedom) mode. The horizontal and vertical winds and the DFDR-recorded EPRs averaged across the three engines were applied by a function generator.

The flight director was in the Approach/Land mode until TOGA was selected. The reconstruction showed that the airplane did not descend below the glideslope until 1805:42, 10 seconds before initial impact. While the flight director was in the Approach/Land mode, the system's glideslope-based logic was providing pitch commands to maintain the airplane on the glideslope and, until 1805:42, the airplane's pitch attitude corresponded essentially to the attitude commanded by the pitch command bars. During the next 2 seconds, as the airplane descended below the glideslope, the pitch command bars moved upward to command a nose-up pitch correction. When TOGA was selected, 7 seconds before initial impact, the airplane was over 3 dots below the glideslope and descending at a rate of about 3,000 feet per minute. The airplane's pitch attitude was 8.3° nose-down and the pitch command bars were commanding an 11.3° nose-up pitch correction.

The Delta L-1011 POM advises flightcrews to use the flight director's TOGA mode to initiate and complete a missed approach from a landing approach. In the TOGA mode, the flight director computers sense the airplane's configuration engine thrust and angle-of-attack, and will position the command bars to command an angle of attack that will maintain the airspeed at or above 1.25 Vs. 24/ Angle of attack is controlled by pitch attitude, and the flight director logic limits the nose-up and nose-down pitch attitudes between 17.5° and -1.2°, respectively. In the TOGA mode, the flight director will, if necessary, sacrifice altitude to maintain the airplane's airspeed at or above 1.25 Vs. At 324,800 pounds, 33° flaps and slats extended, and gear down, 1.25 Vs was 131 KIAS. At 1805:45, when TOGA was selected, the airspeed was about 137 KIAS. During the 7-second interval, the airspeed increased to about 170 KIAS and the rate of increase was essentially linear.

24/ The stalling speed or the minimum steady flight speed at which the airplane is controllable.

About 1 second before TOGA was selected, the first officer had begun a nose-up correction. At 1805:46, 1 second after TOGA was selected, the airplane's pitch attitude had increased from 8.3° to 7° nose-down and the command bars commanded an 18° nose-up pitch correction. During the next 2 seconds, the first officer continued to raise the nose of the airplane; however, at 1805:48, 4 seconds before initial impact, the airplane's angle of attack increased suddenly from about 3° to about 16°. The airplane's pitch attitude was 5° nose-up and the command bars were commanding a 10° nose-up correction. Over the last 4 seconds before initial impact, the airplane's pitch attitude decreased from 5° nose-up to 0° and then increased to 2° nose-up. The pitch command bars lowered and, although they were within 0.13 inch of being centered, they were still commanding a 5° to 6° nose-up correction to an 8° nose-up pitch attitude when the airplane touched down.

1.16.5 Weather Analysis

NOAA provided the Safety Board with an analysis of the weather conditions affecting the landing approach of flight 191. The NOAA analysis, conducted at the request of the Safety Board, was based on its analysis of large-scale meteorological patterns, Geosynchronous Operational Environmental Satellite (GOES) data, weather radar data, airplane weather radar data, flight 191's DFDR data, and an examination of eyewitness accounts of the weather.

The analysis states that the data contained in the NASA wind field analysis:

> shows that the aircraft penetrated the main downdraft of the microburst at 550-850 feet AGL. The aircraft survived the downdraft only to crash in the outburst, or low level outflow of strong winds which contained not only a strong tail wind but a series of three strong wind vortices which were parts of vortex rings which circled the main downdraft.

The analysis states that, "The microburst was in the process of just reaching the surface when Delta 191 entered it."

The analysis states that the thunderstorm involved in the crash was:

> one of a line of discrete cells which extended into the DFW area from the northwest where the line joined a more extensive and intense... complex of thunderstorms along the Red River [about 100 nmi north of DFW Airport.]

The analysis also stated that the "thundershowers" in the immediate DFW Airport area were produced by two storms--Cells "C" and "D"--and that the second storm (Cell "D") was much more severe. The analysis stated, "Further, the first or weaker parent storm (Cell "C") was dissipating just as the second, more intense offspring, was about to become violent."

1.16.6 Flight Attendant's Jumpseat Restraint Systems

Because of the difficulties encountered by the flight attendant in trying to release the restraint system at the R-4 jumpseat, the Safety Board examined the restraint systems at the R-3, R-4, and L-4 flight attendant jumpseats. The other jumpseats had been damaged too extensively to draw any valid conclusions concerning their precrash condition.

The examination of the R-4 and L-4 systems showed that the seatbelt straps were badly worn and damaged, and the shoulder harnesses were stretched and worn, and had been abraded by chafing. In addition, the restraint systems had not been installed in accordance with engineering specifications. The restraint systems had been manufactured in early 1982.

The restraint systems' worn and abraded straps were taken to CAMI and tested for tensile strength with the following results:

> The R-4 seat's left seatbelt strap failed at 1,300 pounds tension for an undetermined reason in the area where it had been jammed inside the adjuster. The strap was designed to a minimum breaking strength of 4,000 pounds; however, FAA Technical Standard Order (TSO) specifies a minimum seatbelt breaking strength of 2,250 pounds and that the entire seat belt assembly (all straps, hardware, and attachments) must be able to withstand a minimum 1,500-pound load without failure.
>
> The R-4 seat's right seatbelt strap failed in the damaged area at 1,850 pounds of tension and below the manufacturer's and the TSO's minimum breaking strength. However, despite this failure, the minimum 1,500 pound load required to fail the entire assembly would not have been compromised.
>
> Each of the L-4's seatbelt straps failed at 2,200 pounds in their damaged areas.
>
> The R-4 jumpseat's right shoulder strap failed in the damaged area at 3,400 pounds or 600 pounds below the manufacturer's minimum standards.

The investigation also disclosed that neither the airline, the FAA, the manufacturer of the restraint system, or the supplier of the strap materials had published guidelines that could be used to determine when the amount of damage or wear would require the replacement of the restraint system's straps.

1.17 Other Information

1.17.1 Air Traffic Control Procedures

FAA Order 7110.65D, Air Traffic Control (hereinafter called the Controllers Handbook) contains the procedures to be followed by ATC controllers. Paragraph 1.1 of the Controllers Handbook states:

> This order prescribes air traffic control procedures and phraseology for use by personnel providing air traffic control services. Controllers are required to be familiar with the provisions of this handbook that pertain to their operational responsibilities and to exercise their best judgement if they encounter situations that are not covered in it.

The Controllers Handbook also establishes duty priorities for the controller. Paragraph 2-2 states:

a. Give first priority to separating aircraft and issuing safety advisories as required in this handbook. Good judgement shall be used in prioritizing all other provisions of this handbook based on the requirements of the situation at hand.

b. Provide additional services to the extent possible contingent only upon higher priority duties and other factors including limitations of radar, volume of traffic, frequency congestion, and workload.

Paragraph 2-2 is annotated fairly extensively. Note 2-2a states in part that given the many variables involved, it is not possible to develop a list of duty priorities that would apply uniformly in any given circumstance. It urges the controller to use his best judgment in prioritizing his tasks, and states, "That action which is most critical from a safety standpoint is performed first."

Note 2-2b states in part that the primary purpose of the ATC system is to prevent a collision between aircraft operating in the system and to organize and expedite the flow of traffic. In addition to its primary purpose, the system can provide additional services (with certain limitations) as cited in paragraph 2-2a above. The system is further limited by the pure physical inability to scan and detect the situations falling into this category. The note concludes, "The provision of additional services is not optional on the part of the controller, but rather is required when the work situation permits."

Additional citations from the Controllers Handbook will be made as required by the subject matter under discussion in the report.

1.17.2 Air Traffic Control Procedures at the DFW Airport Traffic Control Tower

The DFW Airport Traffic Control Tower (ATCT) includes the tower cab and TRACON. The ATCT is a level V facility that provides 24-hour ATC service for the DFW Airport and six controlled satellite facilities.

The TRACON is equipped with a dual radar system; that is, Airport Surveillance Radar System (ASR) 7 and ASR 8 and associated Automated Radar Terminal System (ARTS) III with no continuous data recording capabilities. The tower cab is equipped with a BRITE (Bright Radar Indicator Tower Equipment) radar system which reproduces the ASR display. After the accident all equipment was recertified in accordance with FAA directives and was found to be satisfactory.

The ASR 7 and 8 radars display precipitation intensities at and above VIP level 2 as a milky luminescent area on the radarscope. Both models have weather suppression capability (circular polarization) which, when selected, will suppress the intensity of the precipitation return on the radarscope and decrease the area of the return. At the time of the accident, the ASR-8 was in the circular polarization mode (CP) and the ASR-7 was in the linear polarization mode (LP). The Arrival Radar-1 (AR-1) position and the BRITE display use the ASR-7; the Feeder East (FE) position uses the ASR-8.

Air Traffic Control Position Responsibilities.--Three ATC positions were responsible for providing air traffic services to flight 191 after it was handed off from the Fort Worth ARTCC: Feeder East (FE), Arrival Radar-1 (AR-1), and Local Control East (LCE). The first two positions are located in the TRACON, the third was in the tower cab.

The FE controller was responsible for accepting handoffs into his airspace from the Fort Worth ARTCC. The FE airspace extends from 10 nmi east of DFW Airport to about 35 nmi northeast through southeast of the airport. The FE controller was responsible for maintaining separation and providing radar services to airplanes within his airspace.

The AR-1 airspace begins at the common boundary shared with the FE airspace and extends to the final approach fixes for parallel runways 17/35 and runway 13L/31R. The AR-1 controller accepts handoffs from the FE controller and is responsible for maintaining separation and providing radar services to the airplanes within his airspace.

The LCE controller was responsible for separation between arriving airplanes from the final approach fixes to parallel runways 17/35 and runways 13L/31R. He is also responsible for separating airplanes within the associated landing surfaces of these runways.

Runway Selection.--The tower supervisor is primarily responsible for selecting the active runway(s) at DFW Airport. Determination of active runways requires consideration of all known factors that may affect the safety of takeoff and landing operations such as wind direction and velocity, wind shear alerts, and severe weather activity. The Controllers Handbook, paragraph 3-60, states in part that whenever the surface winds are 5 knots or more, the controller will use "the runway most nearly aligned with the wind." The handbook also notes that "If a pilot prefers to use a runway different from that specified, he/she is expected to advise ATC." This statement is reiterated in paragraph 226 of the AIM.

The 1751 surface weather observation reported a surface wind of 120° at 8 knots. The 1805 observation reported a surface wind of 70° at 8 knots, but the tower supervisor, who was working the LCE position, stated that the wind direction was changing rapidly between 1751 and 1805, indicative of a variable condition. He testified that he was relieved from duty at 1809 and that during the period he was on duty, "The winds were variable, zero six zero to zero nine zero. With a thirty degree variance like that, in my estimation we still were favoring landing south." The Controllers Handbook does not prescribe what actions to take during conditions involving rapidly changing wind conditions, and in circumstances such as this, as stated in part in paragraph 1.1 of the handbook, controllers shall "exercise their best judgement if they encounter situations that are not covered by [the handbook]."

Airspeed Adjustments.--Air traffic controllers are permitted to use speed adjustments to achieve required separation criteria for airplanes under their control; however, the speed adjustments must be within the parameters contained in the Controllers Handbook, and within the air speed minima contained in paragraph 5-102 of the handbook. That paragraph states in part that

> Unless a pilot concurs in the use of a lower speed, use the following minima:
>
> * * *
>
> b. To arrival aircraft operating below 10,000 feet: (1) Turbojet powered aircraft - A speed not less than 210 knots; except when the aircraft is within 20 flying miles of the runway threshold of the airport of intended landing, a speed of not less than 170 knots.

Paragraph 5-103 of the Controllers Handbook authorizes controllers, if conditions require, to request airspeeds below those specified in paragraph 5-102. Paragraph 5-103 states that when this course of action is required, the controller shall use the following phraseology, "If practical, maintain (specified speed) knots or if practical, increase/reduce speed (specified knots) knots."

At 1755:46, flight 191 was requested to reduce speed to 180 KIAS. At 1756:19, the controller requested flight 191 to descend to 5,000 feet "as soon as speed is reduced." Flight 191 responded that they would descend to 5,000 feet "as soon as we slow to one ninety." The controller had never reduced flight 191's speed to 190 KIAS, and he did not comment concerning the reference to an incorrect assigned airspeed.

At 1803:03 and at 1803:46, flight 191 was requested to slow to 160 knots and 150 knots, respectively. The controller did not preface these two requests with the phrase, "if practical." Flight 191 acknowledged the request for 160 KIAS by stating, "be glad to." The subsequent request for 150 KIAS was issued along with an instruction to contact the tower on an appropriate frequency. The flightcrew read back the tower frequency but not the new airspeed. Although the speed request was not specifically acknowledged, the DFDR showed that indicated airspeed was reduced to about 150 KIAS.

The last two requests for airspeed adjustments were made after flight 191 had been cleared for the ILS approach. Paragraph 5-100 of the Controllers Handbook permits controllers to adjust the speed of an airplane after it has been issued an approach clearance when "it is necessary to maintain or achieve desired or required spacing and application of these procedures is preferable to S-turns or discontinuance of the approach. If required, previously issued speed adjustments shall be restated if that speed is to be maintained or additional speed adjustments requested until the airplane reaches the final approach fix or a point 5 miles from the runway, whichever is farther from the runway." A note affixed to this paragraph informs controllers that they are expected to keep speed adjustments in this area to a minimum and then states, "It is the pilot's responsibility and prerogative to refuse speed adjustments that he considers excessive or contrary to the aircraft's operating specifications." Paragraph 272h of the AIM also states that pilots have the prerogative to reject an ATC speed adjustment "if the minimum safe airspeed for any particular operation is greater than the speed adjustment. In such cases pilots are expected to advise ATC of the speed that will be used."

Radar Separation Procedures.--In accordance with paragraph 5-72 of the Controllers Handbook, the minimum required separation between flight 191 and the preceding Learjet 25 was 3 nmi. The AR-1 controller was responsible for ensuring that the minimum 3-nmi interval was not compromised until flight 191 arrived over the final approach fix. From the final approach fix to the runway threshold, separation became the responsibility of the LCE controller. In addition, with regard to flight 191 and the Learjet, paragraph 3-122 of the Controllers Handbook required the LCE controller to "Separate an arriving aircraft from another aircraft using the same runway by ensuring that the arriving aircraft does not cross the landing threshold . . . until the other aircraft has landed and taxied off the runway."

The BRITE display contains mileage markers at 1-nmi intervals along the final approach course; therefore, the LCE controller was able to use the display to monitor airplane separation. The LCE controller stated that although some precipitation was depicted on his BRITE display, he was still able to observe flight 191's ARTS data tag. The controller testified that the spacing between flight 191 and the Learjet was "anywhere from 3 1/2 to 4 miles," and that separation never got below 3 miles.

Since the DFW Airport TRACON radar systems did not have a continuous recording capability, the recorded radar information from Fort Worth ARTCC's NTAP was used to reconstruct the proximate flightpaths of flight 191 and the Learjet. The reconstruction began at 1803:47 and ended at 1805:18, about 37 seconds before flight 191's initial impact. Examination of the reconstruction showed that, at 1803:47, flight 191 was 3 nmi behind the Learjet. The separation decreased to 2.5 nmi by 1804:47 and then increased to 2.63 nmi at 1805:18. The error tolerance of the NTAP data is $\pm$ 0.125 nmi.

Automatic Terminal Information Service (ATIS).--ATIS provides advance noncontrol airport and terminal area operation and meteorological information for use by airplanes arriving and departing an airport and operating within the terminal area by a controller-prepared tape recording which is repeatedly broadcast through a voice outlet. The following information was transmitted by DFW Airport tower ATIS on August 2, 1985, at the time indicated:

> [1647 c.d.t.] Dallas/Fort Worth arrival information Romeo two one four seven Greenwich, weather six thousand scattered, two one thousand scattered, visibility one zero, temperature one zero one, dew point six seven, wind calm, altimeter two niner niner two, runway one eight right one seven left, visual approaches in progress. Advise approach control that you have Romeo.

> [1800 c.d.t.] Dallas/Fort Worth arrival information Sierra two three zero zero Greenwich weather six thousand scattered, estimated ceiling two one thousand broken, visibility one one, temperature one zero one, dew point six five, wind zero four zero at two, altimeter two niner niner two, runway one eight right one seven left visual approaches in progress. Advise approach control you have Sierra.

The 2300 GMT ATIS Sierra message's weather was based on the contract weather observer's 1751 surface weather observation. This observation, transmitted to the tower over the electrowriter, was completed at 1752. The ATIS message weather observation omitted the observations contained in the remarks section of the electrowriter transmission concerning the presence of "cumulonimbus north-northeast, towering cumulus northeast-south-west-north." The message also did not state that ILS approaches to runway 17L were in progress. However, at 1756:28, the FE controller had informed all aircraft on his frequency of this fact and flight 191 had received this information.

Paragraph 1230b(70) of FAA Order 7210.3G, Facility Operation and Administration, states in part that in addition to the basic weather information, i.e., ceiling, visibility, temperature, wind direction, and velocity, etc., the weather data should or can include where applicable "other pertinent information." The Air Traffic Control Assistant on duty in the tower when the 1751 observation was received testified that it was not the tower's policy to include cumulus or cumulonimbus clouds as "other pertinent remarks" in the ATIS because "it's not pertinent information to the safety of a flight," according to the FAA's interpretation of the phrase.

The manager of the FAA's Terminal Procedures Branch stated that it is the FAA's position that "other pertinent remarks" as mentioned in Handbook 7210.3G refers to ". . . remarks about airport or weather conditions which are not readily obvious and would be appropriate to an ATIS broadcast." Examples of these items are tornados, thunderstorms, large hail, moderate to extreme turbulence, and light to severe icing. The manager further stated that remarks referring to cumulonimbus and towering cumulus clouds do not qualify as items required for inclusion on ATIS broadcasts.

<u>ATC Weather Dissemination Duties.</u>--Paragraph 2-100 of the Controllers Handbook states, "Become familiar with pertinent weather information when coming on duty and stay aware of current weather information needed to perform air traffic control duties."

Paragraph 2-101 of the Controllers Handbook requires that a SIGMET and a CWA alert be broadcast on all frequencies except emergency if any part of the area described is within 150 miles of the airspace under the controller's jurisdiction. At the time of the accident, there were no SIGMETs or CWAs requiring that type of handling by the TRACON or local controllers.

Paragraph 2-102 of the Controllers Handbook directs controllers to relay pertinent PIREP information to concerned aircraft in a timely manner and, within a terminal area, to relay all "operationally significant PIREPs" to the appropriate intra-facility positions and to the FSS serving the area in which the report was obtained.

The controller is also urged to solicit PIREPs when requested or when one of the conditions listed exists or is forecast to exist for the controller's area of jurisdiction. One of the listed conditions is "Thunderstorms and related phenomena." Up to and including the time of the accident, the DFW ATCT had not received a PIREP nor had he solicited any from any of the airplanes operating in the vicinity of DFW Airport; however, the NWS forecast for the airport pertinent to the accident indicated a slight chance of a thunderstorm with a moderate rain shower.

Paragraph 2-103 of the Controllers Handbook requires controllers to issue pertinent information on observed or reported weather areas and to provide radar navigational guidance around such areas when requested by pilots. The handbook states, "Do not use the word 'turbulence' in describing radar-derived weather." The handbook recommends that controllers use terminology such as "weather area" or "band of weather" to describe the area of weather and to describe the size of the area in miles. The Controllers Handbook further states that controllers cannot provide precipitation intensity information unless the intensity level "is determined by NWS equipment."

Paragraph 2-106 of the Controllers Handbook limits the type of weather information a terminal area controller can disseminate. The paragraph states in part that he may disseminate general weather information such as "large breaks in the overcast," "visibility lowering to the south," or similar statements that do not include specific values. In addition, "any elements derived directly from instruments, pilots, or radar may be transmitted to pilots or other ATC facilities without consulting the weather reporting station." Specific values, such as ceiling and visibility, can be transmitted only if they are obtained from an official observer or from a weather report issued by the weather station or by a controller certified to make visibility observations.

At 1756:28, the FE controller had broadcast to all airplanes that "there's a little rain shower just north of the airport and they're starting to make ILS approaches. . . ." At 1759:44, he broadcast in part, "there's a little bitty thunderstorm sitting right on the final; it looks like a little rain shower." Flight 191 received the first transmission but not the second since it had been cleared from the frequency 7 seconds earlier. However, at 1759:47, flight 191's first officer stated, "We're gonna get out our airplane washed." The captain asked "What?" and, at 1759:51 the first officer repeated "We're gonna get our airplane washed."

The FE controller's radar system was in CP mode and he testified that his advisories concerning the weather to the north of the field were based on a precipitation return he had observed on the adjacent AR-1 radarscope since it did not appear on his radarscope. He testified that the word "little" was meant to describe the size of the storm. "We normally would describe [precipitation] as light, moderate, heavy, we wouldn't use the word little to describe an intensity of [precipitation]."

With regard to his use of "thunderstorm" in the 1759:44 transmission, the FE controller testified, "I had no factual information that a thunderstorm was there, consequently I had no right to call that to him as a thunderstorm." With regard to the precipitation return, he testified that it did not move across the radarscope to its position north of the airport, "it just popped up." The FE controller testified he did not solicit PIREPs about a thunderstorm because he did not know one existed and he was not aware one was forecast.

There are no windows in the TRACON, and the FE and AR-1 controllers had not received any reports of thunderstorms near the airport. About 1800, a controller returning from a duty break had observed lightning through a window in the tower building. He returned to the radar room and told the area supervisor of what he had seen. The area supervisor testified that the returning controller did not describe what he had seen in detail. He had merely stated that there was lightning outside and suggested that possibly the facility should shift to backup power. The area supervisor testified that "Lightning anywhere in the area would be a threat to [commercial] power," and that it was routine procedure to switch to backup power anytime the TRACON's commercial power source might be threatened.

The AR-1 controller testified that on assuming the position about 1800 he observed a precipitation return outside the outer marker north of the airport on his radarscope. He could not describe the return as a cell "because there wasn't one. It was just a patchy light precip return." He testified that he cannot report a thunderstorm based solely on weather returns on his radarscope; however, once he has been advised "that a particular area has been confirmed as a thunderstorm," he can use "thunderstorm" when making advisories to traffic.

At 1800:36, the AR-1 controller asked flight 351 if it was able to see the airport. The flight replied, "As soon as we break out of this rainshower we will." According to the controller this was the first information he had received concerning the weather north of the airport. Both of these transmissions were overheard by flight 191. At 1803:30, the controller broadcasted "And we're getting some variable winds out there due to a shower . . . out there north end of DFW." This transmission was also overheard by flight 191.

The LCE controller testified that he saw what appeared to be light rain about 5 to 8 miles north of the airport about 1750. Then, "toward [1800] . . . an area of rain developed to the northeast approximately three miles," and the rain was depicted on his BRITE.

The LCE controller testified that when flight 191 reported to him initially (1803:58), he did not inform the flightcrew of the rain shower because they had reported that they were in the rain, and therefore, "there was no reason to tell him he was in the rain." He testified that the first time he saw lightning was about the time that the Learjet preceding flight 191 landed. It was one cloud-to-ground strike about 1.5 miles east of runway 17L and "appeared to be on the outer edge" of the shower.

The LCE controller testified that the tower is responsible for reporting changes in visibility and that all the controllers and supervisors serving in the tower cab are qualified and certified to take visibility observations. Such an observation is required if the visibility about "the majority of the area encompassing the airport drops below four miles. . . ." Paragraph 2-105a, Controllers Handbook states, in part, as follows:

> a. When the prevailing visibility at the usual point of observation, or at the tower level, is less than 4 miles, tower personnel shall take the prevailing visibility observations and apply the observations as follows:
>
> (1) Use the lower of the two observations (tower or surface) for aircraft operations.
>
> (2) Forward tower visibility observations to the weather observer.
>
> (3) Notify the weather observer when the tower observes the prevailing visibility to decrease to less than 4 miles or increase to 4 miles or more.

The first communication between the tower cab and the TRACON concerning weather north of the airport occurred at 1803:58, when the area supervisor in the tower cab called the TRACON area supervisor on the coordination telephone line and stated "We've been busy with these SWAPs and hadn't paid any attention but that is heavy heavy rain off the approach end of both runways, just for your information." The area supervisor in the tower testified that he did not notice the rain until his attention was called to it by a controller working the west side of the airport's runway complex. He testified that he had not seen the rain "due to the duties I was performing with the SWAP, helping the data people, and moving strips to the other side of the airport . . . I had no idea there was any rain out there." He testified that he did not see any lightning nor did he hear thunder before the accident occurred.

Minimum Safe Altitude Warning (MSAW) System.--The MSAW System at the DFW Airport provides a visual and aural warning to controllers if an airplane's actual or projected altitude is, or will be, below 394 feet AGL within a rectangular area 1 mile either side of the centerline of runway 17L and between 2 nmi and 5.1 nmi north of the runway end. The system is a part of the ARTS III computer and provides warnings only for airplanes equipped with an altitude encoding transponder (Mode C) provided the airplane is being tracked by the ARTS computer.

The DFW MSAW system does not record individual warnings. The tower controllers on duty during flight 191's approach stated that flight 191 generated no warnings and the DFDR data showed that neither flight 191's actual altitude nor its projected altitude exceeded the warning parameters of the MSAW system.

Controller Workload.--The ATC transcripts provided 15 minutes 15 seconds and 4 minutes 44 seconds of the FE and AR-1 positions' radio transmissions and receptions, respectively. During these periods the FE and AR-1 controllers handled about 216 and 67 radio calls and transmissions, respectively. Both controllers described their workloads as moderate.

The LCE position's transcript began at 1802:48, and at 1805:56, the LCE controller directed flight 191 to go around. During that period, the LCE controller handled 44 radio calls and transmissions. The LCE controller described his workload as moderate.

The line of thunderstorms located beyond and to the east of the DFW Airport's terminal area had caused the Fort Worth ARTCC to impose SWAP procedures which affected all eastbound departures. The weather was such that the eastbound departures were limited to one departure route, and airplanes were being dispatched along that route with a 30-nmi separation. During this period, a developmental controller was working the LCE position under the supervision of the assigned tower team supervisor. Since the developmental controller had never worked the local control position under such conditions, the team supervisor took over the LCE position at 1750 so that the developmental controller could observe how to handle this situation. Because of the restrictions imposed on the eastbound departures, by 1800, a large number of airplanes were stopped along the taxiways leading to runways 17R and 17L. According to one departing captain, he counted at least 20 airplanes ahead of his position at or just after 1800.

About 1800, an additional eastbound route was released from SWAP restrictions. In an effort to move their traffic, the controllers handling the airport's east runway and runway access complex began to move airplanes to the west side of the airport for departure. To further expedite departures, the LCE controller also decided to use runway 17L for some of the newly released eastbound departures, and to use runways 17R and 17L for takeoffs. One of the two missed approaches mentioned earlier was caused by a takeoff airplane which had not cleared the runway in time to allow a landing; the other was caused by the failure of a landing airplane to clear the runway as expeditiously as the LCE controller had hoped. In addition, since the local controller is responsible for the surfaces of runways 17L and 17R, given the direction of traffic, the LCE controller could not release airplanes landing on runway 17L to ground control until the airplanes had crossed runway 17R en route to the ramp.

1.17.3 Delta Air Lines Flight Operation Procedures and Training

The Delta flight operations procedures are contained in Delta's Flight Operations Procedures Manual and Delta's Lockheed L-1011 POM.

The Supplemental Information Section of the POM contains the company policy regarding thunderstorm avoidance. The POM states, in part, that when a flight encounters thunderstorm conditions, "detour the area if possible. When early evasive action is not practical, apply the following suggested minimum clearance distances to avoid areas where sharp changes in rainfall intensity are indicated . . . Below 10,000 feet, avoid areas by 5 miles." The Delta Systems Manager for Training was asked, "is there any distinction made between flying below 10,000 feet and flying on an instrument approach?" The Systems Manager testified, "That's not specifically addressed."

The Supplemental Information Section of the POM also addresses wind shear. After defining wind shear, the section discusses both takeoff and landing wind shears. The landing wind shear section is divided into two segments: increasing and decreasing performance wind shears. According to the manual, an increasing performance shear is one "which results in the aircraft having a tendency to increase airspeed and/or overfly the glide path." A decreasing wind shear, however, is "one which results in the aircraft having a tendency to decrease airspeed and/or underfly the glidepath."

The POM states in part that when wind shear analysis or PIREPs indicate the presence of a decreasing performance shear, the pilot should apply a wind additive to the reference speed equal to the amount of airspeed loss expected, not to exceed 20 knots. (If more than 20 knots is anticipated, a course of action other than landing in shear conditions should be considered.) It advises the pilot to be prepared to apply thrust immediately to maintain a minimum of Vref when encountering the shear and to be prepared for a prompt reduction of thrust once normal target speed and glide path is reestablished. The POM states, "If below 500 feet AGL in shear conditions and glideslope deviation exceeds 1 dot below or above, missed approach should be initiated."

With regard to the increasing performance shear, the POM states that when it is encountered causing an airspeed increase and an above-glideslope deviation, "do not unspool the engines," and be prepared to apply thrust when normal target speed and glide path is reestablished. The POM then restates the glideslope warning cited above.

The POM further advises, "The above procedures for landing in wind shear are general guidances to be followed. Good judgement might dictate a go-around at any point in the approach and landing phase if conditions appear less than safe."

The recommended procedures for initiating a missed approach are contained in the flight training section of the POM. When the decision to initiate a missed approach is made, the POM states in part that the pilot should press the TOGA switch, apply go-around thrust while rotating to the climb attitude, retract the flaps to 22°, and retract the landing gear after establishing a positive rate of climb.

On May 5, 1986, Delta issued a temporary revision to the POM changing the previous guidelines for initiating a missed approach during low level wind shear encounter. The temporary revision states,

> As a direct result of new information gained during the recent Delta Flight 191 accident, certain changes are being made to Delta's wind shear guidelines. These wind shear guidelines will remain under review for possible future changes as additional information is received and new data is developed.

The revision states that "Delta's policy concerning wind shear continues to be that we must AVOID SIGNIFICANT WIND SHEAR." The revision then provides the following guidance to pilots concerning flight path control:

> Proper flight path control can also provide a sound basis to determine the existence of wind shear in turbulent conditions. The following criteria concerning unstabilized flight path control are published as guidelines to the existence of significant wind shear. These criteria are specifically uncontrolled changes (not pilot induced) from a normal takeoff, a normal climb-out or a normal stabilized approach condition.
>
> Criteria for Unstabilized Flight Path Control
>
> o Uncontrolled changes from normal in excess of:
>
> - Plus or minus 15 knots indicated airspeed.
> - Plus or minus 500 fpm vertical speed.
> - Plus or minus 5 degrees pitch attitude.
> - Plus or minus 1 dot glide slide displacement.
> - Plus or minus 10° heading variation.

Below 1,000 feet AGL, be prepared to execute a missed approach if you encounter either:

- o Severe turbulence or
- o Indications of unstabilized flight path control

On May 5, 1986, the same guidelines were sent to flightcrew members on all other aircraft operated by Delta.

Wind Shear Ground Training.--Wind shear training is administered to Delta flightcrews both during recurrent ground training and in the company's flight simulators. According to the Delta Systems Manager for Training the ground training course in wind shear originated in 1975. At that time, Delta developed an audio-visual slide tape presentation based on the information contained in the FAA's AC 00-50 "Low Level Wind Shear" and this tape was presented to all their crews in a safety seminar. On January 23, 1979, the FAA revised the material in the advisory circular and issued the new material in AC 00-50A (See appendix G). Delta revised its audio-visual presentation and presented it to its flightcrews during recurrent ground training. In addition to this program, the company has presented to its flightcrews other audio-visual tapes and films on the subject of wind shear.

On May 4, 1976, Delta issued Flight Operations Bulletin No. 76-25 to all its pilots. The subject of the bulletin, which is still in effect, is Spearhead Echo and Downburst Near the Approach End of Runway 22L at JFK Airport on June 24, 1975. The 25-page bulletin, a condensation of a research paper prepared by Dr. T. Theodore Fujita of the University of Chicago, was based on his investigation of the meteorological data involved in the crash of Eastern Air Lines flight 66, a Boeing 727, at John F. Kennedy Airport, Jamaica, New York, on June 24, 1975.

Delta also publishes a bimonthly publication Up Front that is issued to all Delta cockpit crews. According to the Systems Manager, the company's policy is to make items of timely interest available to all of its pilots, and Up Front is one of the main vehicles for doing this. The publication has included articles on the aerodynamic effects of heavy rain, wind shear, and microbursts. One of the articles on microbursts stated in part, "Microbursts occur from cell activity. Do not take off or land directly beneath a cell, whether it is contouring or not." The article also contained the following disclaimer: "This article does not necessarily reflect the views of Delta Flight Operations."

The Systems Manager was asked, "Considering these two statements, is there anywhere in Delta's program where they officially tell pilots not to take off or land directly beneath a cell?" The Systems Manager replied,

> I think it's implied, and can certainly be inferred, that if we tell pilots to avoid thunderstorm activity by five miles below ten thousand feet, that that would be in that. I see nothing in this article which conflicts with Delta policy. It's just that that is a generic statement stating that this is not an official Delta policy statement, this is an article written by someone who is functioning in a capacity other than as a spokesman for Delta.

He was also asked if he or whoever is responsible for the contents of Up Front would permit anything to be published therein which would be contrary to the Delta training procedures or policies. He responded, "No."

Wind Shear Simulator Training.--Delta's flight simulators are programmed with six approved FAA wind shear models; the most severe of these, FAA No. 10, is modeled on the wind shear constructed as part of the investigation of the Eastern flight 66 accident. The conditions contained in FAA Model No. 10, as simulated, were realistic and the recommended wind shear penetration procedures, if followed, would result in a successful escape from the programmed wind shear condition.

The recommended procedures taught in Delta's simulator program are based on the procedures contained in FAA AC 00-50A. The procedures require the pilot to maintain a pitch attitude that will prevent altitude loss and if needed, to apply all available power. The procedures recommend that the pilot trade airspeed for altitude by maintaining or increasing the airplane's pitch attitude, if necessary, to an angle that causes the stall warning stickshaker to activate. Thereafter, the recommended technique advises the pilot to lower the nose of the airplane just enough to silence the stickshaker and to maintain that pitch attitude until the airplane exits the wind shear environment.

Delta flightcrews receive wind shear training in the simulator during their Line Oriented Flight Training (LOFT) periods and, if sufficient time is available, during their "training-in-lieu of proficiency check" simulator periods. Wind shear training, by regulation, is not required by the FAA on the proficiency check, and the actual training received by individual pilots is not documented in company training records. The instructor who administered the last simulator periods of the captain and first officer of flight 191 was unable to recall whether they had conducted approaches under wind shear conditions during those training periods.

The Systems Manager stated that he was concerned that simulator wind shear training might possibly be a subtle form of "negative training" because it could lead pilots to conclude that adherence to the recommended procedures would always result in a successful escape from a wind shear environment. He later testified that he "was not convinced one way or the other. I don't feel that I'm capable of making that judgment, and I think a good human factors analysis should be made." He further testified that the basic reason for providing the training was

> that if everything else failed in avoidance . . . inability to predict, or to forecast, or to detect a wind shear condition, and [the pilot] found himself surprised by an encounter, we wanted to give him the best possible tool to work with in flight path control and maximizing his performance so that he could recover from the encounter.

Airborne Weather Radar Training.--According to the Systems Manager, the company's ground school training curriculum for both initial transition into an airplane or upgrade training for crewmembers includes the basic description of the radar equipment and the functions of the controls used to operate the equipment. "Where possible we provide the manufacturer's literature on the use of the radar set."

The System Manager further testified,

> But with any airborne radar device, written instructions and classroom academics are highly inadequate. What you really need is hands on experience in the real world, practicing with the use of the set, adjusting antenna tilt, learning what the difference is between weather radar returns . . . and ground returns, and . . . the lines you get from interference from other radar transmissions. It's largely something that has to be learned by experience.

The Systems Manager testified that the minimum range setting on the Lockheed L-1011's Bendix RDR-1F radar system was 50 nmi, and at that setting, the system incorporated a 25-nmi range marker. He testified that he used the radar in the L-1011, and that he did not find it to be very useful between the outer marker and the runway during an instrument approach. He testified that the:

> minimum range of fifty miles leaves you with a rather small image when you are within ten to fifteen miles of the airport. The primary use of this type of radar, or with any airborne radar that I have any experience with, is en route weather avoidance. When you get into the approach environment, especially in the final approach stage, you are in a . . . heavy task burden of the flight, and to get any useful work out of the radar you have to do an awful lot of playing with the antenna tilt, and [since] you are also very close to the ground . . . you get a lot of ground return. So, it's the least useful in the approach phase of flight.

The Bendix RDR-1F manual contains a description of the equipment and its operating controls, and pictures of different types of weather radar returns that may be obtained and viewed on the radarscope. The manual does not contain any limitations regarding the use of the radar with the 50-nmi range selected, nor any cautionary language concerning returns obtained within 5 to 10 nmi of the airplane while in the 50-nmi range setting. The manual does recommend the following with regard to the arrival phase of flight:

> a. Surveillance of weather formations located in the airport areas should be accomplished as soon as possible.
>
> b. In terminal areas stabilization errors may be introduced by required maneuvers that are outside of stabilization limits.

Delta's Flight Operations Procedures Manual contains the following:

> Use of Radar in Thunderstorm Conditions - Thunderstorm conditions should be avoided whenever possible. If early evasive action is not practical, the following practices should be followed:
> - Avoid areas where sharp changes in rainfall intensity occur, any echoes which are rapidly changing shape, size, or intensity, or any echoes which have prominent scallops, hooks or fingers by at least:
>   5 miles at 10,000 feet or below.

The manual states that these clearances are predicated on using "the 50 or 100 mile range on the L-1011."

The manual states that weak echoes or areas of weak rainfall gradient may be flown through or adjacent to "if judgement dictates this to be the most desirable procedure." It also states that when taking off in a thunderstorm area, the radar should be operated on the ground using upward antenna tilt to determine the best possible climb-out path.

Cockpit Resource Management.--Cockpit resource management refers to the "effective management of available resources by the flight deck crew." 25/ It refers to

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25/ Lauber, J.K., "Background and Statement of the Problem," in Cooper, G.E., White, M.D., and Lauber John K., Eds., Resource Management on the Flight Deck. NASA CP-2120, 1979.

using all equipment, information, and flightcrew personnel to enhance pilot decision-making, communication, crew interaction, and crew integration. Although the Federal Aviation Regulations do not require cockpit resource management training, a number of United States air carrier companies have integrated this type of training into their ground school or simulator training programs, or both.

The Delta training program does not specifically address cockpit resource management or assertiveness training; however, simulator instructors were expected to identify individual weaknesses during simulator exercises and take corrective action. During the investigation, a Delta official stated that Delta's training department was surveying current airline industry training practices and hoped to formulate its own program in the future.

1.17.4 Low Level Wind Shear Detection Systems--Air and Ground

The FAA's Integrated Wind Shear Program Plan is to reduce the low-altitude wind shear hazard through research, technology development, education, and training. The FAA program is designed to provide the aviation community with procedures and methods to identify and avoid low-altitude wind shears and, if wind shear is unavoidable, to apply the best procedures to cope with it. The program can be categorized as follows: ground detection systems; airborne detection and pilot guidance systems; and information, education, training, and operating procedures. The Safety Board believes that the present status of the projects contained in the program should be reviewed in this report.

Ground Detection Systems.--To date, the only viable ground detection systems are the LLWAS and the pulse Doppler microwave radars.

Of the proposed 110 LLWASs 85 have been installed, with the remaining systems to be installed by the end of 1986. Work is continuing to improve the LLWASs. The number of sensors has been increased in the systems at Denver and New Orleans, and data recording systems have been installed to evaluate the performance of the enhanced systems. In addition, within the next 2 years, data recording systems will be installed on 54 LLWASs.

The FAA is examining the performance of the sensors and their location geometry as a part of the Microburst and Severe Thunderstorm (MIST) project currently being conducted at Huntsville, Alabama. The MIST project is examining the performance of algorithms designed to improve the presentation of LLWAS displays in control towers. According to the FAA, by May 1987, the improved wind shear detection algorithms and display concept for the standard six-sensor LLWAS will be fully operational. An adjunct of the MIST project is the examination of the meteorological factors involved in microbursts which occur in a wet humid climate.

During the summer of 1987, the FAA will conduct a field test of the enhanced or Advanced LLWASs (an LLWAS containing more than six sensors) at Denver and New Orleans. The test will include the following: an evaluation of new wind shear detection and identification algorithms; an investigation of the potential of the Advanced LLWAS to estimate the loss or gain of aircraft performance in terms of runway-oriented headwind, tailwind, and crosswind components; evaluation of new display concepts; and the development of automated monitoring of the LLWAS's performance.

The only available equipment that can detect and track a microburst throughout its entire cycle is the pulse Doppler microwave radar. These radars will be installed in the ATC system under the Next Generation Radar (NEXRAD) program. The NEXRAD system consists of 130 units. The first radar will be installed in February 1988 and the last in August 1992.

The NEXRAD system, because of the station spacing and the geometry imposed on radar beams by the curvature of the earth, will only permit radar coverage down to an altitude of 6,000 feet; as a result, about 40 high-priority terminals would not be protected by the system. Protection for these terminals has therefore been included in the Terminal Doppler Radar Program.

One hundred and ten radar systems are included in the terminal program; however, the first delivery of these radars is not planned until December 1991. Because of this delivery date, the FAA has developed a plan to accelerate the placing of Doppler radars at selected terminals. Thirteen NEXRAD radars that have been modified for terminal area use will be sited to cover 16 terminals throughout the United States. (In three instances, one radar will cover two terminals.) Essentially, the performance of the modified NEXRAD radars (Terminal NEXRAD radars) and the proposed Terminal Doppler radars are equivalent. The Terminal NEXRAD radars will be replaced as the Terminal Doppler radars are delivered.

Airborne Systems.--Three airborne wind shear detection systems are presently either certified by the FAA or will be presented for certification by the FAA.

The Safe Flight Instrument Corporation, White Plains, New York, has developed a wind shear warning and guidance system that has been evaluated by a number of United States airlines. The system has been certificated under 14 CFR Part 23, Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes. The system is currently in use on corporate airplanes operating under 14 CFR Part 91, General Operating and Flight Rules.

Last year, the Sperry Rand Corporation, New York, New York, received a supplemental type certification for its wind shear detection and alert system, and is installing it on Piedmont Air Lines Boeing 737s. The system is part of the airplane's performance management system. An amber light alerts the pilot of an impending wind shear. The pilot is warned of more severe conditions by a flashing red light and an aural warning. The system does not provide guidance to the pilots to penetrate a shear, but Sperry and Piedmont are working on the addition of a guidance capability.

The Boeing Company, Seattle, Washington, has also developed a wind shear alert system which also provides control guidance to the pilot if the shear is penetrated. The system has not been used in-flight, but its performance capabilities have been demonstrated in the company's engineering simulator. The alerting system monitors the horizontal and vertical components of the wind and provides aural and visual warnings. The red warning light illuminates simultaneously with the aural warning and remains on until the stickshaker margin is greater than 4° angle of attack, and the alert system is armed at rotation and is deactivated above 1,000 feet radio altimeter height. Enhanced flight director control laws supply guidance to the pilot whenever the flight director is placed in the takeoff/go-around mode. When the airplane rate of climb is less than 600 fpm, the flight director commands pitch attitude to about 15° until the airspeed decreases to the point where the angle of attack is within 2° of that required to activate the stickshaker. If the airspeed continues to decrease, the pitch command bar will command a decreased pitch attitude to maintain the angle of attack 2° below stickshaker activation.

The Boeing wind shear training will stress that the best strategy to follow when receiving the alert is to initiate a missed approach even if the pilot has not yet determined a wind shear on his instruments.

The two airborne detection systems discussed in this section represent the current level of technology in that they can only warn the flightcrew after the airplane has entered a shear condition of some predetermined magnitude. The FAA and NASA have jointly initiated a program which, among other objectives, will provide the necessary information for industry to produce certifiable wind shear systems and procedures to detect hazardous wind shear on board the airplane. According to the Integrated Wind Shear Program Plan, these systems "include forward looking systems." Among the candidate sensors cited in the plan for this type of system were "radar, laser, acoustics, and infrared." The plan states that further investigation of airborne warning systems will continue; however, target dates for these projects have not been established.

The Safety Board and most of the air carrier and aviation community have recognized the importance of pitch control in a wind shear encounter. The Safety Board has recommended to the FAA and industry the need to develop cockpit instrumentation that will not only warn the pilot of a wind shear but will also provide the pitch guidance that will permit the pilot to extract the maximum performance from his airplane. The Safety Board is pleased to note that cockpit instruments that provide warnings of impending wind shear have been developed and certified and that pitch guidance systems are being developed.

<u>Information, Education, Training, and Operating Procedures.</u>--In May 1986, the FAA submitted to industry a draft of its proposed education, training, and operating procedures for comment. In addition to educational information concerning the recognition and avoidance of low-altitude wind shears, the draft proposes guidelines for initiating a go-around when a wind shear is encountered. The suggested guideline parameters include altitude, abnormal power applications, glideslope deviations, aircraft pitch attitudes, and indicated airspeed which, if exceeded, would require the pilot to initiate a go-around. However, these parameters are not mandatory for the aviation community and, depending on the comments of the community, they may be modified or not included in the plan.

After the FAA receives and evaluates industry's comments, it will prepare and issue manuals containing wind shear information, training materials, and operating procedures to airline managers, training departments and instructors, and flightcrews. The FAA will also issue a video presentation concerning wind shear recognition, avoidance, and penetration techniques for use when a wind shear is encountered. Ultimately, this information will be modified as required and made available to the entire aviation community. The manuals and video presentations will be issued in February 1987.

The Safety Board is gratified to note that, in addition to the areas discussed above, the Integrated Wind Shear Program Plan has funded further investigation into the aerodynamic effect of heavy rain on airfoils, as well as projects to develop technology that will reduce the time required to transmit weather information from the ground to the airplane. The Safety Board believes that the Integrated Wind Shear Program Plan will, if pursued diligently, contribute greatly to reduce the hazards associated with low-altitude wind shears and urges the FAA to continue its excellent efforts to complete the program promptly and expeditiously.

2. ANALYSIS

2.1 General

The airplane was certificated, equipped, and maintained in accordance with Federal regulations and approved procedures. There was no evidence of a malfunction or failure of the airplane, its components, or powerplants that would have affected its performance.

The flightcrew was certificated properly and each crewmember had received the training and off-duty time prescribed by FAA regulations. There was no evidence of any preexisting medical or physiological conditions that might have affected the flightcrew's performance.

The ATC controllers on duty in the DFW Airport TRACON at the time of the accident were certificated properly and each controller had received the training and off-duty time prescribed by FAA regulations. All of the controllers providing ATC services to flight 191 were full performance level controllers.

The NWS meteorologists were qualified, and the contract weather observer at DFW Airport was certificated by the NWS.

Based on the evidence, the Safety Board directed its attention to the meteorological, airplane performance, air traffic control, and operational factors that might have caused the airplane to descend and crash, and to occupant survival. The meteorological evidence relevant to this accident included the weather conditions at DFW Airport at the time of flight 191's approach, the weather information provided by the NWS to ATC, the weather information provided by ATC to flight 191, and the flightcrew's use of the airplane's weather radar system. For continuity and clarity, aspects of the latter two weather-related areas--the weather information provided by the ATC to flight 191 and the use of airplane weather radar systems--are discussed during the Safety Board's examination of ATC and operational factors.

2.2 Meteorological Factors

Weather at DFW Airport.--On final approach to runway 17L at DFW Airport, flight 191 penetrated a weather cell containing a thunderstorm with a heavy rain shower. Because of the evidence that two weather cells (Cells "C" and "D") were present north of runway 17L, the Safety Board examined the possibility that Cell "C" might have masked Cell "D" from flight 191's flightcrew.

At 1752, the Stephenville weather radar data indicated that a weak (VIP level 1) weather echo (Cell "D") developed about 2 nmi northeast of the approach end of runway 17L. The center of the echo was about 6 nmi northeast of the end of the runway. This was the closest echo to the approach end of runway 17L and at 1752, it contained only light rain showers.

At 1800, when the Stephenville radar specialist had returned to his radarscope from other duty requirements, the weather echo had intensified to a very strong echo (VIP level 4). At 1804, the radar specialist called to inform the NWS Fort Worth Forecast Office of the presence of the echo, its intensity, and that its top was 40,000 feet. At or very shortly after 1805, flight 191 penetrated the rain shaft falling from this weather echo.

During the Safety Board's public hearing, the radar specialist said that another, weaker weather echo was located north of Cell "D" and about 6 nmi northeast of the airport. He testified that, based on the 1800 radar photograph, Cell "C" looked "like maybe a VIP [level] two [echo]," but could not state that the smaller echo would mask the larger cell from a southbound airplane. None of the ground witnesses who had viewed the north side of the storm described the presence of any clouds or any additional areas of precipitation in the vicinity of the north side of the storm. The captain of flight 539 following flight 191 testified that he was 5 to 6 miles behind flight 191 when flight 539 turned on final and that he kept flight 191 in sight until it entered the rain shower beneath the buildup. He also testified that he saw lightning in the area where he lost sight of flight 191. His first officer stated that when they turned on final, a cell containing "abundant lightning" was directly off the approach end of runway 17L, and he saw flight 191 "penetrate the cell." Based on the evidence the Safety Board concludes that the cell at the end of runway 17L was not masked from flight 191 by an intervening weather cell.

At 1803:58, flight 191 reported to the tower and stated that they were "in the rain," and at 1805:20, a sound similar to rain was heard on the CVR. Since that sound was not heard at 1803:58, the Safety Board believes that the rain did not intensify until 1805:20. At 1804:18, the first officer reported seeing lightning "coming out of that one." When questioned by the captain he again used the term "that one" to describe the origin of the lightning and then informed the captain that the lightning was "right ahead of us." The Safety Board believes that the language used by the first officer indicated that he was able to see the cloud or cell that was emitting lightning and that the flightcrew still had forward visibility until the rain intensified at 1805:20.

Wind Field Analysis.--The analyses of the airplane's performance and inertial parameters recorded on the DFDR conducted by both Lockheed and NASA were consistent and showed that the horizontal winds affecting flight 191 veered from an easterly to a northerly direction. During the descent, a maximum headwind component of about 26 knots was encountered at 754 feet AGL. The headwind component then decreased, changed to a tailwind, and the maximum tailwind component of 46 knots occurred near the first impact point. Since the airplane's ground speed was increasing at this time, it was probably still within the outflow at impact.

Based on the rotation of the wind direction along the airplane's flight path, the center of the outflow was located about 1,000 feet west of the airplane's ground track and 12,000 feet north of the approach end of runway 17L. Flight 191 encountered the northern edge of the outflow at 1805:14 when its headwind component began increasing rapidly. At 1805:14, the ATC radar plot showed flight 191 was about 9,900 feet from the first touchdown point and about 11,300 feet from State Highway 114. Since witness statements indicated the precipitation did not reach the highway until after flight 191 went across it, and since flight 191 was still within the outflow at first impact, the Safety Board concludes that the southern edge of the outflow was between the first impact point and the highway and about 11,000 feet from the northern edge of the outflow.

The wind field showed that flight 191 flew through the outflow of a thunderstorm. The horizontal dimensions of the outflow were about 11,000 feet (3.4 kilometers) and since the airplane's track passed close to the center of the outflow, the diameter of the outflow, assuming symmetry, was also about 3.4 kilometers. Based on its size, this outflow can be classified as a microburst. The vertical winds affecting the flight included a maximum downdraft of 49 fps, which occurred at 590 feet AGL followed at 560 feet AGL by the maximum updraft of 25 fps. Within the next 8 seconds, the airplane experienced a 22-fps downdraft, a 16-fps updraft, a 42-fps downdraft, and a 18-fps updraft.

The evidence indicates that flight 191 entered the microburst at 1805:14 and crashed at 1805:52. During that 38 seconds, it encountered a horizontal wind shear of about 72 knots. In addition, the six rapid reversals of vertical winds and the 20° right-wing-down roll during the final portion of the descent showed that the airplane penetrated a vortical wind flow.

The LLWAS.--The Safety Board considered the possibility that the LLWAS did not function properly and that, given the location of the microburst, its alarm should have sounded earlier.

The LLWAS was recertified the morning after the accident. In addition, beginning August 12, 1985, and over the next 6 weeks, the wind velocity-measuring components of all the LLWAS's wind sensors were checked and recalibrated where required. All of the boundary-located sensors were found to be accurate. The centerfield sensor's wind direction-measuring components were accurate, but the sensor's speed-measuring components read 4 knots low; therefore, the LLWAS was more sensitive in computing any wind shear alarm. Since the centerfield sensor was reading 4 knots low, a lesser magnitude of wind at the two northern sensors was required to produce the 15-knot vector difference required to place the system into alarm.

The LLWAS did go into alarm after flight 191 crashed. One controller stated that the alarm began as the rain moved across the north end of the field and by the time he checked the display, all sensors were in alarm. Other controllers stated that it did not sound until after the storm moved across the field, and that when they checked the display, all sensors were in alarm. Regardless, the LLWAS was operational and did alarm. Given the location of the microburst and the fact that the southern edge of the microburst's outflow was about 2,000 feet north of the northeast sensor when the airplane first impacted, the LLWAS could not have provided any timely wind shear warning to the flightcrew of flight 191.

The Delta Air Lines Meteorology and Dispatch Departments.--The Delta dispatcher on duty had tried unsuccessfully to call up the Stephenville radar site on his Kavouras monitor at 1745 and 1750. Between 1750 and the time of the accident, he did not try to call Stephenville again. Since the dispatcher did not have any new or different weather information to provide to flight 191, he did not try to contact the flight as it approached DFW Airport, nor was he required to.

The Fort Worth Forecast Office.--The aviation forecaster on duty at the Fort Worth Forecast Office became aware of the storm cell northeast of DFW Airport about 1804, after he overheard the radar specialist at Stephenville describe the cell to the public and State forecaster. He then observed the cell on his television monitor.

The aviation forecaster testified that during the day he had watched numerous cells build to VIP level 4 and then dissipate without receiving any ground truth reports of thunder, hail, or winds that met the criteria for requiring an aviation weather warning. The cell northeast of DFW Airport did not, in his judgment, seem any different from those he had observed earlier, and therefore he decided not to issue an Aviation Weather Warning to DFW Airport.

The aviation forecaster testified that he considered the intensity of a radar weather echo to be "merely an indicator" of the severity of a storm and that, in the absence of ground truth reports attesting to the presence of thunder, hail, or both, he would not label a VIP level 4 radar weather echo a thunderstorm. Given the criteria for issuing an Aviation Weather Warning and the fact that, in the forecaster's judgment, Cell "D" did not seem to be different from the VIP level 4 echoes he had observed earlier, the Safety Board can only conclude that the aviation forecaster's decision not to issue an Aviation Weather Warning was reasonable.

In addition, except for Carswell Air Force Base, the Fort Worth Forecast Office was responsible for issuing Aviation Weather Warnings to all of the airports in the Dallas/Fort Worth metropolitan area, and none of these airports were depicted geographically on either the office's weather radar display or map overlays. Despite the fact that the aviation weather forecaster knew the location of DFW Airport, the Safety Board believes that all NWS offices that have an aviation weather warning responsibility should have the airports for which they are responsible clearly located on a map for each weather radar display in the office.

The Center Weather Service Unit.--The Fort Worth ARTCC's CWSU was staffed in accordance with the levels agreed upon by the FAA and NWS. On the afternoon of August 2, 1985, the CWSU was staffed by an NWS meteorologist and an assistant traffic manager serving as the weather coordinator. Since the ATC personnel assigned to the weather coordinator position are not trained or qualified to interpret the weather or to observe the CWSU's RRWDS, no one was available to monitor the RRWDS when the meteorologist went to the cafeteria for his meal break about 1725 until he returned about 1810, 4 to 5 minutes after flight 191 crashed.

The meteorologist, even if he is the only one on duty in the CWSU, is allowed a meal break in addition to those required for other personal needs. In this case, before leaving the CWSU, the meteorologist had assured himself that there were no thunderstorms threatening any of the airports in the Dallas/Fort Worth area and that the line of thunderstorms well east of Dallas, with which he had been concerned, was relatively stable. The radar photographs confirm his evaluation of the situation.

During the meteorologist's absence, Cell "D" developed and began to grow and intensify. At 1752, it was a small VIP level 1 radar echo. At 1756, Cell "D" was a VIP level 3 echo, and about 1800, the Stephenville radar specialist saw the echo and classified it VIP level 4. Given the 2-minute delay in receiving Stephenville data on the RRWDS, Cell "D" would not have been portrayed on the RRWDS as a VIP level 4 until about 1802. The CWSU meteorologist testified that, based on Cell "D's" location and rapid growth rate, he would have issued a CWA when it had intensified to a VIP level 4 if he had been on duty at the RRWDS and had observed the cell's development. However, if routine notification procedures were used, the CWA would have reached the TRACON and tower cab between 1807 and 1812, which was after flight 191 crashed. The CWSU meteorologist further testified that in this case he would have issued the CWA by telephone to the DFW tower supervisors. Had he done this, the CWA might have reached the DFW Tower about 1802 or 1803. ATC procedures require a CWA to be broadcast on all frequencies; therefore, assuming that the information was processed promptly, the TRACON and local controllers probably could have broadcast "an all airplanes on the frequency" weather alert between 1803 and 1805, possibly in time for the crew of flight 191 to receive it before they entered the rainshaft and microburst.

The Safety Board believes that the meteorologist's decision to take a meal break was understandable and not imprudent, given his assessment of the weather condition at the time. Further, the Board is not certain that, given his other responsibilities, the presence of the meteorologist at his station would have assured his immediate observation of the cell buildup. Finally, the Board is hesitant to accept this NWS-to-ATC-to-pilot communication channel as a primary circuit for observation and transmittal of rapidly changing dynamic weather conditions. Use of this channel presumes that the information telephoned to a tower facility can be immediately conveyed to the appropriate local controller and further transmitted to the appropriate flightcrew within several minutes or less. We believe this to be a false presumption in view of the controller's workload and total responsibility, and that more effective weather observations and communication capabilities are needed. This is, and has been, the basis for Safety Board recommendations that address the need for weather information to be directly available at the local controller's stations and ultimately for providing a ground-to-air data link.

Nonetheless, until the ATC towers are better equipped and staffed to define and disseminate to flightcrews the weather in the immediate vicinity of the airport, the NWS and CWSU systems remain the key elements in providing severe weather information to flights approaching and departing the airport. Therefore, the Safety Board believes that immediate steps can be taken to improve the efficiency of the system. The Board believes that both the CWSU and major tower facilities must be sufficiently staffed with meteorologically qualified personnel to continuously monitor weather radar and to facilitate the immediate communication of severe weather information to the controller who is in radio communication with flights close to or in the area of the weather.

There are 20 CWSUs throughout the contiguous United States and one in Alaska. The Safety Board's investigation disclosed that some of these offices have obsolete, and in some instances inadequate equipment to display and interpret satellite and radar information. Because of the importance of the CWSUs to aircraft safety, the Safety Board urges the FAA to ensure that the CWSUs have the best possible data and display capability with which to ensure the safety of the National Airspace System.

2.3 Air Traffic Control

The major ATC issue requiring examination by the Safety Board was the weather dissemination procedures of the ATC controllers who had provided services to flight 191. However, before proceeding with any analysis of that issue, the following additional issues required Safety Board examination.

The equipment used by the ATC controllers was functioning properly at the time of the accident. All positions within the TRACON were staffed properly, and the tower cab's assigned supervisor was working the local control east position at the time of the accident. Examination of the facility showed that tower cab supervisors routinely work control positions in order to maintain proficiency, to train developmental controllers, and to provide relief during dinner periods. In this instance, there was another supervisor qualified to serve as a supervisor in the tower cab. Though he was not assigned officially to serve in this position, he did perform voluntarily some of the routine tasks that devolve on the tower team supervisor. The Safety Board found no evidence to indicate that any required duties had been omitted.

Runway Selection.--The tower supervisor is primarily responsible for selecting the active runway and, according to Paragraph 3-60 of the Controllers Handbook, the controller will use "the runway most nearly aligned with the wind." During the 20 minutes before the accident, the winds were about 10 knots or barely exceeding that value. The wind direction, with regard to the parallel 17/35 runways, was essentially a direct 90° crosswind which, from time to time, varied about 20° either side of the 90° crosswind. The tower cab's supervisor testified that before he was relieved at 1809 the winds had been variable from 60° to 90° and "with a 30° variance like that, in my estimation we still were favoring landing south." Given the light wind speed, the winds provided a very small tailwind component, if any. The Safety Board believes that the 60° wind direction may have favored a north landing; however, given the low speed and the varying direction of the wind, and the other conditions involved in changing the direction of traffic, we find little if any evidence to indicate that the supervisor's decision to continue south-landing operations was imprudent or improper.

The Safety Board recognizes that the LLWAS centerfield sensor used by the controllers for runway surface wind information was providing speeds that were 4 knots below the actual wind velocity. However, this fact was not known to the controllers; therefore, their reliance on the centerfield sensor to provide wind information to pilots and for runway selection criteria cannot be faulted. The contract weather observer's wind sensor, which recorded wind velocity but not direction, was located within 40 feet of the centerfield sensor. Until 1750, the weather observer's sensor recording showed that the wind speeds were at or below 5 knots. Between 1750 and 1810, the wind speeds averaged about 10 knots, while the prevailing wind direction during that period, as reported by the controllers, varied from 60° to 90°. Consequently, the resulting average crosswind component was about 9.5 knots, although the headwind and tailwind components varied from about 1 knot to 3.5 knots, respectively. These three wind components were within the demonstrated and allowable wind limitations for takeoff and landing of virtually all air carrier aircraft operating at DFW Airport. If they were not, or if any pilot operating at the airport was uncomfortable with the reported surface winds, it was the pilot's responsibility to inform the controllers of his objections and intentions. One flightcrew did question the direction of landing; however, after being informed of the varying surface winds, the captain elected to continue and to land without any further objection or report of concern.

Airspeed Adjustments.--The Controllers Handbook did not prohibit controllers from requesting a turbojet airplane to slow to 150 KIAS. All that is required is to preface the request with the phrase "If practical." The controller did not do so and thus failed to comply with the provisions of the Controllers Handbook. Nevertheless, with or without the use of the proper terminology, if the pilot cannot comply with the request, either because of airplane operational limitations or weather, it is his duty to inform the requesting controller that he cannot comply. Since the captain of flight 191 accepted the speed adjustments without complaint, the Safety Board must assume that he did not consider them a threat to the operation or safety of his airplane, and the Board concludes that the speed adjustment requests were not causal to the accident.

Because the runway 17L ILS approach's outer marker is located 5.1 nmi from the end of the runway, the controllers were authorized to use speed restrictions for separation until flight 191 reached the marker. The evidence showed that the last speed restriction requested was issued before flight 191 reached the outer marker.

Radar Separation.--The applicable separation standard between flight 191 and the Learjet was 3 nmi and the traffic controllers stated that the standard separation never compromised. Although the LCE controller's BRITE display had 1 nmi markers along the approach course, it is difficult simply to look at the radarscope and determine separation to the nearest tenth of a mile.

The recorded radar data from the Fort Worth ARTCC indicates that a loss of separation between flight 191 and the Learjet occurred inside the ILS's outer marker. The minimum distance between the two airplanes was 2.5 nmi at 1804:47, increasing to 2.63 nmi at 1805:18. The maximum error tolerance in the recorded data was plus or minus 0.125 nmi. Based on these data, a loss of separation may have occurred; however, the Safety Board concludes that it had no bearing on the accident.

Automatic Terminal Information Service.--The weather contained in ATIS messages was taken from the contract weather observer's surface weather observations. The investigation confirmed that, pursuant to FAA policy, weather remarks contained in the airport's surface weather observations were not included in the ATIS message. For example, the remarks section of the 1751 surface weather observation stated that cumulonimbus and towering cumulus were located to the north and east of the airport. At 1800, ATIS message Sierra was issued. Except for the description of the cumulonimbus and towering cumulus clouds, Sierra contained the entire 1751 surface weather observation.

The FAA order describing the contents of ATIS messages states that weather data should or can include, where applicable, "other pertinent information." The FAA representative testified that "other pertinent remarks" refers to weather conditions which are not readily obvious and thus appropriate for an ATIS broadcast, such as tornados, thunderstorms, large hail, moderate to extreme turbulence, and light to severe icing. Therefore, ATIS Sierra as issued was in compliance with applicable FAA policies.

However, the Safety Board takes exception with the FAA position, noting that a thunderstorm would be a proper ATIS entry. Cumulonimbus and towering cumulus are convective clouds which can easily and very quickly become thunderstorms. Even without the presence of lightning and thunder, they should be avoided, and the Safety Board believes that the FAA should reconsider its position on this issue. The Safety Board also notes that the Federal Meteorological Handbook, No. 1, Table A3-8A, states that remarks concerning "cumulonimbus clouds" are significant to the air traffic controllers.

Given the timing of ATIS Sierra, flight 191 never received Sierra; therefore, the Safety Board concludes that the omission of the cumulonimbus and towering cumulus from the message played no part in causing the accident. By the time Sierra was issued, flight 191 was on a downwind leg for runway 17L, and the cloud area described in the 1751 surface weather observation should have been as apparent to the flightcrew as it was to the weather observer.

ATC Weather Dissemination.--The ATC controller is responsible to disseminate weather that he or she observed either visually or on radar pursuant to the limitations contained in the Controllers Handbook. The ATC controller also is responsible for ensuring that all significant weather messages, i.e., SIGMETS, PIREPS, CWAs, and such, are relayed on all frequencies if any part of the area described in the messages is within 150 miles of the airspace under the controller's jurisdiction. At 1800, on August 2, 1985, there were no such significant weather messages at the DFW Tower to relay.

The Terminal Area Approach Control.--Since the TRACON has no windows, the only sources of weather information available to personnel on duty would be weather information and messages from the NWS, the airport's surface weather observation, PIREPs, the observations of the tower cab controllers, and precipitation returns on the two radar systems. Since precipitation returns degrade the quality of the information needed by controllers to perform their first priority duty of traffic separation, ATC radar systems are not designed to enhance them and, in fact, incorporate circuitry which suppresses the intensity and decreases the area of the precipitation return, i.e. circular polarization. Thus, when a precipitation return appeared on the TRACON radarscope, other than knowing that the precipitation in the area was of sufficient intensity to be painted by the radar, the controller had no way to estimate the intensity of the precipitation creating the return. To classify the return area as a thunderstorm, he needed additional information from another source. At the time of the accident, the only information available to the FE and AR-1 controllers was the information on their radarscopes.

With regard to other sources of information, about 1800, the TRACON supervisor was told by a controller returning from a scheduled break that he had seen lightning near the airport. The returning controller did not locate the source of the lightning nor did the supervisor question the controller for details. The supervisor merely viewed the evidence of the presence of lightning as a potential threat to the TRACON's commercial electrical power and ordered the facility switched to back-up power, a routine precaution under these circumstances. The traffic control positions were not informed of the returning controller's observation. Given the fact that other and more authoritative sources of weather information such as the tower controllers, pilots, and NWS observers had not reported the existence of severe weather in the immediate vicinity of the airport, the Safety Board does not consider the actions of the radar room supervisor unreasonable.

The first description of the weather to the north of the field was received by the TRACON from an outside source at 1803:58 when the area supervisor in the tower cab called the TRACON and reported "heavy rain off the approach end of both runways, just for your information." There was no mention of either lightning or thunder.

Both the FE and the AR-1 controllers reported the presence of the rain shower off the north end of runway 17L. At 1756:28, the FE controller issued an "all aircraft listening" transmission describing a "little rain shower just north of the airport . . . they're starting to make ILS approaches. . . ." This transmission was received by flight 191. At 1759:44, the FE controller told flight 539 "there's a little bitty thunderstorm sitting right on the final; it looks like a little rain shower." Flight 191 did not receive this transmission.

The Controllers Handbook contains recommended phraseology for controllers to use to describe the appearance of weather echoes on their radars. The phraseology is designed to make the pilots aware of the areas of precipitation depicted on their radarscopes, not to analyze what is causing the return or its intensity. If the controllers are provided more specific information from either NWS, CWSU, or PIREPS concerning the depicted areas, they may use that information to describe the radar depiction. Since the FE controller had not received any reports of a thunderstorm, he testified that his use of "little bitty thunderstorm" at 1759:44 was improper. He also testified that he normally used the words light, moderate, or heavy to describe precipitation intensity and he used "little" with "rainshower" to describe the size of the precipitation area.

The CVR transcript showed that the FE controller informed flight 191 of the weather lying off the north end of runway 17L. The Safety Board believes that the use of the adjective "little" might have, despite the controller's stated intention, been interpreted by the flightcrew as a description of the severity of the rainfall rather than the size of the precipitation area. However, the Safety Board also notes that the 1756:28 transmission should have indicated that the shower's intensity had decreased the visibility in the area to the point that ILS approaches were now required to land at DFW Airport.

The ATC transcript showed that the AR-1 controller had, at 1803:30, broadcast a message that the airport was experiencing some variable winds due to a shower just beyond the "north end of DFW." This transmission was received by flight 191. The terminology used by the AR-1 controller contained no quantitative modifiers and did describe with reasonable accuracy the radar portrayal on which the advisory was based.

The Tower Cab.--At 1803:58, flight 191 established radio contact with the LCE controller, stating, "Tower, Delta one ninety one heavy, out here in the rain, feels good." The LCE controller testified that he did not report the presence of the rainstorm to flight 191 because the flight had reported that it was in the rain and was therefore as aware of the weather conditions as he was.

Two of the ATC personnel in the tower cab working the airport's east complex observed lightning before the accident. This type of information, when possessed by controllers, should be passed on to the weather observer, the TRACON, and to arriving and departing pilots. The air traffic control assistant saw lightning, but was unable to state the precise time she saw it. The control assistant said that the lightning occurred sometime between 1800 and the accident. The control assistant did not bring the sighting to the attention of the LCE controller.

The LCE controller also saw lightning between the time the Learjet landed and the time he saw flight 191 emerge from the rain shower. At 1805:44, the local controller asked the pilot of the Learjet to "expedite" his landing roll; therefore, the Learjet probably landed about 1805:14. At 1805:56, the local controller instructed flight 191 to "go around," so he saw the lightning sometime during that 42-second interval. Since lightning is a significant meteorological event and also indicates that the cell discharging the lightning has reached thunderstorm level, the local controller should have reported its occurrence. Had the LCE controller reported his sighting to flight 191, it probably would not have altered the outcome since the flight entered the microburst windfield about 1805:14.

Several air carrier flightcrews at DFW Airport saw lightning to the north of the airport. While it is not possible to fix the precise times of the sightings, the evidence indicates that these sightings preceded the accident by 2 to 5 minutes. One of these flightcrews also believed they saw a tornado; however, this sighting was just before the accident. None of the flightcrews reported these sightings to the tower.

The flightcrew of an air carrier flight which landed about 4 minutes before the accident saw lightning on either side of their airplane after passing inbound over the outer marker on their landing approach to runway 17L. After landing, this flightcrew stated that they observed a phenomenon which they described as a "waterspout." However, the flightcrew did not report either the waterspout or lightning to the tower after landing.

Had any of these flightcrews delivered a PIREP to the DFW Tower concerning these meteorological events, the TRACON and tower cab controllers would have been required by regulation to repeat the PIREP to all airplanes on their respective frequencies immediately. Some of these flightcrews were on the local control frequency when they observed these events. Had they reported their observations at any time after 1804, flight 191's flightcrew would have overheard the PIREP, and depending on how quickly it was reiterated, they would have also overheard the controller's required repetition of the PIREP. The Safety Board concludes that had the captain of flight 191 received PIREPs describing lightning near the airport and the sightings of a "tornado" and a "waterspout" north of the airport, he probably would have rejected the approach and maneuvered his airplane to avoid the rain shaft below the thunderstorm. Therefore, the Safety Board concludes that the failures to provide the captain with these PIREPS was causal to the accident.

The Safety Board also notes that comments from pilots, as well as the lack of adverse comments, affects the way controllers handle weather information. Not once before the accident did any pilot request to discontinue his approach, elect to hold elsewhere awaiting improvement of the weather, or provide any adverse comments to ATC personnel after landing. If pilots continue to accept instructions or routes which require weather penetrations, the controllers can only assume the route is acceptable. When flight 191 reported on initial contact with the LCE controller that it was in rain and that it "feels good," it was, in essence, a PIREP, but one without adverse comment. The transmission showed that the pilot was aware of the rain and that the rain was not creating any problems.

2.4 Operational Factors

The Safety Board's examination of the Delta wind shear training program showed that while the curriculum discussed the necessity of avoiding wind shears, it also recognized that in some instances a pilot might inadvertently encounter one. As a result, its simulator curriculum taught the procedure of using maximum thrust, increasing the airplane nose-up pitch attitude, and allowing airspeed to decrease to near stickshaker speed if necessary to avoid ground contact, and lowering the nose slightly if the stickshaker was actuated. Wind shear training, as it existed at Delta before the accident, was in agreement with accepted industry standards. Although the captain's and first officer's training records did not show that they received this training, they probably received it during their LOFT and recurrent training periods. The captain's instructions to the first officer concerning the impending loss of indicated airspeed after they penetrated the microburst's windfield and his subsequent commands to apply full power tend to corroborate that he, at least, had received this training.

Wind Shear Avoidance.--The precise location and moment that a microburst will occur cannot be forecast. As of this date, a forecast technique has been developed that allows meteorologists to predict the type of day on which a microburst is likely; however, the technique does not permit the meteorologist to state what time and where the microburst will impact. Furthermore, this forecast technique only applies to the high plains dry microburst and may not apply to the moist, humid areas of the United States. Since the most violent wind shear activity is associated with convective weather, and since microbursts are a product of convective activity, the best way to avoid the microburst type of shear is to avoid flying under or in close proximity to the convective type of clouds, i.e. cumulonimbus, towering cumulus, and in particular, thunderstorm.

The Delta Flight Operations Procedures Manual states that below 10,000 feet, thunderstorms are to be avoided by 5 miles. Furthermore, the Delta company publication Up Front published an article on microbursts which stated in part, "Microbursts occur from cell activity. Do not take off or land directly beneath a cell, whether it is contouring or not." Although the article contained a disclaimer, Delta's Systems Manager for Training stated that the article was not contrary to company policy and, in addition, Delta would not permit material contrary to the company's flight procedures and policies to be presented to its flightcrews in Up Front.

Airborne Weather Radar.--The evidence concerning the use of the airborne weather radar at close range was contradictory. At the public hearing and during a later deposition, testimony was offered that the airborne weather radar was not useful at low altitudes and in close proximity to a weather cell, whereas, with regard to the RDR-1F system which was on flight 191, the manufacturer's maintenance manual did not contain any cautionary language regarding the use of the set at close range with the minimum range setting.

At least three airplanes scanned the storm at very close range near the time of the accident. The radars used were the Bendix RDR-4A color radar, which unlike the RDR-1F contains a 20-nmi range setting. However, the RDR-1F will contour and the RDR-4A will display red at about the same level of reflectivity. All three of the airplane's radars painted the storm as an area of solid red with few or no transitional color areas. The captain of the flight behind flight 191 was able to view the storm on his radar when his airplane was at or approaching the outer marker.

At 1759:37, flight 191 was about 7 nmi northeast of the cell and was requested to turn right to 340°. Between 1751 and 1800, the cell had intensified from a VIP level 1 to VIP level 4, and flight 191's nose was pointed at the cell until 1759:37. Except for a period between 1755:53 and 1757:19 during which a portion of the checklist was being completed, the flightcrew was relatively free of in-cockpit duties. During this period the flightcrew would have been free to use the weather radar to scan the cell and to manipulate the antenna tilt to acquire the best possible radar picture. Since the storm cell had reached a VIP level 4 by 1800, the cell would have reached contouring levels of intensity for their radar sometime during this period. However, the CVR contains no conversation referring either to what was or was not displayed, difficulties involved with manipulating the radar antenna tilt, or the inadequacies of the radar in this area of flight. Since it is also possible that the flightcrew did try to use the radar but did not engage in any discussion over the results of the attempt, the Safety Board is unable to determine if the radar had been turned off, or whether the flightcrew tried to use it during the final moments of the descent and as the flight approached the outer marker. Furthermore because of the conflicting evidence, the Safety Board cannot determine the capability of the weather radar in a low-altitude, close-range weather situation.

Operational Decisions.--The Safety Board's investigation has documented the weather information which was either not transmitted to the flightcrew or, because of the time constraints involved in making the observation and transmitting the data was unavailable to the flightcrew. Regardless of the information which was not disseminated to the flightcrew, the primary issue facing the Safety Board was whether the information that was available to the flightcrew and the captain, either through their own observations or from ATC during the descent and approach to the DFW Airport, sufficient for them to assess the developing weather situation along the final approach to runway 17L and then make a proper decision either to continue the landing approach or to take alternate action. The Safety Board believes they did have sufficient information to make this assessment.

The forecasts provided on departure advised the flightcrew that the atmosphere around the DFW Airport was unstable and capable of producing an air mass thunderstorm. By 1756:28, after receiving an ATC "all aircraft" broadcast, the flightcrew knew that localized shower type of precipitation, precipitation that results from convective activity, was in progress north of the DFW Airport and that it was of sufficient intensity to impair in-flight visibility and to require that ILS approaches be made to runway 17L. The facts showed that within the next 4 minutes, the crew became aware that they would have to fly through the precipitation area to land, that the shower was still in place, and that its intensity had not decreased since ILS approach procedures were still required.

During the descent, the buildup causing the shower was visible to the flightcrew. Since the flight approached from the east and, when it was about 5 nmi northeast of the buildup, was vectored by ATC to an upwind leg, a downwind leg, and a base leg before being vectored to the final approach course, the flightcrew should have been able to get a good view of the storm cell and its dimension.

When flight 191 turned final the flightcrew heard the AR-1 controller's broadcast to all aircraft that the shower was just north of the airport and was affecting the surface winds, and 3 seconds later one of the flightcrew members said that the "stuff was moving in." Forty-nine seconds later the first officer reported that he saw lightning coming from a cloud or clouds "right ahead" of the airplane, and 42 seconds after that the rainfall intensified enough that it could be heard on the CVR. By this time the captain should have known that the rain was coming from a buildup or buildups over and directly in front of the airplane, that these were the buildups which produced the lightning that prompted the first officer's PIREP, and that the buildup or buildups contained a thunderstorm. The captain also had to know that the thunderstorm was between his airplane and the airport and, according to company policy, should be avoided.

Since the approach was continued, it would seem that the captain did not consider the observed lightning, when placed within the context of all the other available information, of sufficient importance to execute a missed approach. In an attempt to understand why the captain made the decision, which in retrospect was improper, the Safety Board examined the factors which affect how pilots make decisions. A NASA technical memorandum described this decisionmaking process as follows:

> . . . in order to accomplish any task, a pilot must first seek and acquire information from whatever sources are available. He must then make some determination regarding the quantity, and the quality, of the information he has gathered. Previously gathered knowledge, contained in his memory, will influence the determination of whether he had enough information, of high enough quality, to allow him to proceed. Psychological or environmental stress can also influence his evaluation of the information.
>
> Having determined that he has enough information, and that it is reasonably reliable, the pilot must then process these data in predetermined ways (again based on memory) in order to reach a wise decision from a limited number of alternatives. Before he finally accepts the decision he has made, however, he will make some judgment as to the acceptability of the candidate decision in terms of its potential impact upon the likelihood of successful mission completion. If the decision is finally accepted, the pilot selects the ways in which he will implement it, and then takes appropriate actions.
>
> A large part of this process involves the pilot's judgment of probabilities; he is attempting to make wise decisions, often in the face of uncertainty. In addition, he must consider cost and safety tradeoffs, and there is good evidence that all of these factors do influence decisionmaking in the aviation system. 26/

In this case, conflicting information was available to the captain. The weather information, as provided by the controller and observed by him, showed a rapidly developing thunderstorm. The discussion in the cockpit showed that the crewmembers were aware that the rain was of sufficient intensity to "wash the airplane" and it was moving toward the airport. Finally, based on just what was visible, they knew they were going to penetrate an "opaque rain shaft" which had lightning associated with it.

26/ A Method for the Study of Human Factors in Aircraft Operation, TM X-62, 472, National Aeronautics and Space Administration, September, 1975.

The captain had to be aware of the company policy concerning thunderstorm avoidance. Indeed, given the prudent conduct he had exhibited earlier in the flight, the Safety Board believes that had this cell been positioned farther from the airport, providing him with more space to maneuver and still land, it was a cell he would have avoided. However the position of the storm did not allow him that luxury. Thus, given the company's stated thunderstorm avoidance policy, he would have had to reject the approach and hold till the storm moved off. Since he had adequate fuel to hold for about 20 minutes before leaving for his alternate, the airplane's fuel supply did not require him to fly the approach at this precise moment.

Upon landing at Dallas, the flightcrew was scheduled to fly to Orlando, Florida. Because the Orlando trip was scheduled to depart DFW Airport at 1957, a 20-minute hold would not have imperiled their availability for the flight. However, a diversion to their alternate would have, and this could have influenced the captain's appraisal of the weather between him and the airport.

Other factors could have influenced the captain's appraisal of the weather. There had been no report of LLWAS-detected wind shears during the flight's decent. However, the controllers had begun reporting wind gusts and although the speed of the gusts was not excessive, the fact that they had just begun marked a change in the weather.

Flight 191 was one of a stream of airplanes landing at the airport, and all of these airplanes had landed without reporting difficulties or unusual conditions on the approach. The two airplanes just ahead of flight 191 had landed without reported difficulty. This fact could have led the captain to believe that, despite its appearance, the storm did not contain any dangerous weather or that the dangerous portion of the cell was still moving toward the approach course but had not, as yet, reached it.

When the lightning was reported and the heavy rain encountered, flight 191 was within 4 nmi of the end of runway 17L. Since there had been no reports that the weather had reached the airport, and, in fact, it had not, the airport was clear. Given his airspeed, he was within 2 minutes of landing and he might have decided that his exposure to the observed weather would be minimal.

All of these factors may have led the captain to misappraise the weather and to ignore one other factor, which he should have known intimately, especially given his experience and the fact that most of Delta's route structure lies in areas where severe convective storms occur often. Convective-type storm cells are volatile; therefore, a preceding airplane may encounter little if any weather but the following airplane can encounter a fully developed storm. The captain should have been well aware of the volatility of these storms and of the risk of basing a decision on the actions of a preceding captain.

The Safety Board believes that the captain had sufficient information to appraise the weather along the ILS localizer course to runway 17L. The Safety Board believes that the captain's misappraisal of the severity of the weather could have resulted from any, or a combination of, the factors cited above.

Although the Safety Board believes the accident could have been avoided had the procedures contained in the Delta thunderstorm avoidance policy been followed, the absence of more specific operational guidelines for avoiding thunderstorms in the terminal areas provided less than optimum guidance to the captain and flightcrew. The circumstances of this accident indicate that there is an apparent lack of appreciation on the part of some, and perhaps many, flightcrews of the need to avoid thunderstorms and to appraise the position and severity of the storms pessimistically and cautiously. The captain of flight 191 apparently was no exception. Consequently, the Safety Board believes that thunderstorm avoidance procedures should address each phase of an air carrier's operation and, in particular, the carriers should provide specific avoidance procedures for terminal area operations.

While it is the captain's responsibility to decide either to continue or discontinue a landing approach, the Safety Board believes that in this case, it was a flightcrew decision. Both the first and second officers were aware of the weather astride the final approach course and 1 minute elapsed between the time the first officer reported sighting lightning and the entry into the microburst windfield. Either the first or second officer had ample time to inform the captain that they believed that the approach should be discontinued. Given the fact that the captain was described as one who willingly accepted suggestions from flightcrew members, the Safety Board has no reason to believe that his demeanor would have influenced either man to delay or withhold suggestions to him relative to the safety of the airplane. Since these suggestions were not forthcoming, the Safety Board believes that neither officer saw any reason to suggest that the approach be discontinued and that they concurred with the captain's intent to continue. Therefore, the flightcrew was responsible for the decision.

The Safety Board has long advocated providing cockpit resource management training to captains and assertiveness training to first officers. Since Delta does not provide this type of training, formally, to its flightcrews, the Safety Board carefully examined the CVR transcript and the prescribed L-1011 operational procedures. While the Board's examination has shown that the suggestions cited above were not forthcoming, it also disclosed that there was a free and unrestricted transfer of information among the flightcrew members, that observations relating to the weather were made without apparent reservation, that the checklists were called for and completed promptly, and that there was no breakdown in flightcrew coordination procedures. Although in this instance the lack of formal cockpit resource management and assertiveness training was not causal to the accident, the Safety Board believes that this training is necessary to ensure the proper exchange of information among flightcrew members and should be provided by the air carrier companies.

Decisions During the Approach.--The analysis of the flight recorder data shows that, at 1805:05, about 45 seconds after the first officer's observation of lightning, the airplane began to encounter an increasing headwind component. The airplane was descending through about 875 feet AGL on the ILS glideslope at 150 KIAS (Vref + 13 knots). The onset of the increase was gradual, but between approximately 1805:12 and 1805:19 the headwind component increased more rapidly at a rate of about 2.7 knots/second. During this 7-second period, the airplane accelerated to about 173 KIAS, and the first officer retarded the throttles. By 1805:15, all three engines were either at, or very near, flight idle EPR. During the first part of this period, the first officer also had applied a gradual nose-down control correction. The pitch attitude decreased from about 4° nose-up to 1.3° nose-up and then began to increase as the first officer began to apply nose-up control corrections. At or shortly before 1805:19, the airplane encountered a strong downdraft. The vertical winds changed from a 10-fps updraft to a 20-fps downdraft. The first officer's response was to apply further nose-up control correction, and the pitch attitude increased to about 7° nose-up. At 1805:19, as the airplane entered heavy rain, the captain warned the first officer, "watch your speed," which was followed almost immediately by the more definitive comment, "you're gonna lose it all of a sudden, there it is." The airplane performance analysis shows this comment referred to a significant loss (44 knots) of indicated airspeed in 10 seconds as the airplane traversed the increasing headwind, followed by downdraft, and then by decreasing headwind wind shear. Since the captain was familiar with this type of wind shear from recurrent ground and simulator training and based on information provided in Delta's L-1011 POM, the Safety Board concludes that, although he may not have anticipated an encounter with a microburst, the captain was quick to recognize its manifestations. The Safety Board concludes also from the captain's commands to push the power up--"way up, way up, way up"--following the predicted loss of airspeed, that he was familiar with the actions needed to restabilize the airplane on the glideslope.

At 18:05:29, as the airplane was descending through about 650 feet AGL, the decreasing trend of the headwind reversed itself which, along with a high thrust condition, resulted in a rapid increase in airspeed from about 129 to 140 KIAS. As a result, at 18:05:31, thrust was reduced (from an engine pressure ratio of 1.47 to 1.33) to counter the rapidly increasing airspeed. The airplane momentarily stabilized on the glideslope despite airspeed fluctuations of +20 knots to -44 knots and downdrafts from 15 to 40 fps as it descended through the heavy rain. Consequently, the Safety Board concludes that the flightcrew probably believed that the airplane had penetrated the worst of the windshear, that the airplane would emerge shortly from the heavy rain, and that continuation of the approach was warranted. Also, it concludes that these beliefs may have been prompted by the flightcrew's wind shear training and simulator experience in which they had successfully flown through microburst demonstrations that had incorporated the classic downburst outflow with its increasing headwind, downdraft, and decreasing headwind, and subsequent restabilization of the aircraft.

Based on his wind shear training and L-1011 simulator experience with wind shear encounters, the captain's decision to continue the approach was understandable following momentary stabilization of the airplane above 500 feet AGL at 1805:31. However, within the next several seconds, the flight encountered a second severe disturbance subsequently identified as the vortex ring consisting of large variations in wind components along all three axes of the airplane. Indicated airspeed decreased from 140 to 120 knots, the vertical wind reversed from a 40-fps downdraft to a 20-fps updraft, and a severe lateral gust struck the airplane. This gust resulted in a very rapid roll to the right, which required almost full lateral flight control authority to counter and to level the wings. Consequently, the airplane's angle of attack increased from 6° to approximately 23° degrees, and most likely increased more rapidly, and to a higher value, than recorded by the DFDR because of the rate-limited angle of attack sensors. The severe environment that flight 191 encountered during the 5 seconds after 1805:31 most likely prompted the captain to say, "Hang onto the (nonpertinent word)" at 1805:36. Also, at this time, the flightcrew probably first considered the execution of a missed approach, but they were likely too occupied with the immediate task of maintaining control of the airplane in the turbulence to audibly express these thoughts. However, engine thrust had been applied and the airplane momentarily rose slightly above the ILS glideslope. Six seconds after the captain's above comment, with engine thrust at or near maximum, the airplane began a rapid descent which was not arrested until ground contact 10 seconds later, at 1805:52. The Safety Board believes that the audible command TOGA issued by the captain 3 seconds after the glideslope departure, and 9 seconds after maximum thrust had been applied, may have been confirmation of the missed approach and an indication that he had switched the flight director from the approach/land mode to the TOGA mode.

The Safety Board is concerned that the present training within the industry for wind shear encounters on the final approach seems to advocate the philosophy that the retrieval of the approach profile is the desired end result and not escape from the environment. For example, the landing wind shear procedures in the Delta L-1011 POM advised the pilot "to be prepared to apply thrust immediately to maintain a minimum of Vref when encountering the shear and to be prepared for a prompt reduction of thrust once normal target speed and glide path is reestablished." The Safety Board believes that training should emphasize that in an environment wherein extreme pitch attitude changes and large applications of engine thrust are required to maintain altitude and minimum airspeeds, flightcrews should be taught that the only objective of the procedure is to escape and thereafter place the maximum distance between the ground and the airplane as soon as possible. In this regard, the Safety Board notes that the revision to the Delta wind shear procedures issued after the accident provides Delta flightcrews with additional criteria to determine when the airplane's flight path control has become destabilized. The revised procedures advise the flightcrews to be prepared to execute a missed approach below 1,000 feet AGL if they encounter either "severe turbulence or indications of unstabilized flight path control."

Airplane Control During Microburst Penetration.--Delta and most major air carriers taught their flightcrews to trade airspeed for altitude if they inadvertently encountered low-altitude wind shear. This technique was practiced in the simulators, including the L-1011 simulators, and flightcrews were taught to increase the airplane's pitch attitude and to add maximum thrust if necessary to control the airplane's flightpath. If necessary to avoid ground contact, the pitch attitude could be increased until the stickshaker activated and then decreased slightly to an attitude which would silence the stickshaker. Thereafter, the airplane's pitch attitude should be kept at an attitude just below that which would reactivate the stickshaker until the end of the wind shear area was traversed.

The first officer was apparently able to apply the above techniques to keep the airplane on the ILS glideslope as it passed through and beyond the initial portion of the microburst. When the airplane descended into the vortex, the combination of an airspeed loss of 20 KIAS and a strong updraft most likely caused a momentary (1-second) activation of the stickshaker. The Safety Board believes that the first officer acted reflexively when the stickshaker activated to exert a 20- to 25-pound forward push on the control column. This control column force and the longitudinal stability of the airplane resulted in the airplane nosing over to a -8.5° pitch attitude, a rapid departure from the ILS glideslope, and a descent rate which approached 5,000 fpm for an instant.

The NASA analysis of alternate flight paths showed that ground impact might have been avoided had the pushover force not been applied. However, the Safety Board recognizes that the airplane was in an extremely turbulent environment, and because of the rapid reversals of the vertical winds, the airplane was subjected to rapid changes in angle of attack, longitudinal pitch forces, and fluctuations of indicated airspeeds. Consequently, under these circumstances, the ability of the first officer to apply an optimum or recommended pitch control technique would have been subjected to a severe test.

The flightcrew had applied maximum thrust shortly before the airplane departed rapidly from the glideslope, and the captain called for TOGA within 3 seconds of glideslope departure. When TOGA was engaged, the command bars presented a "fly-up" command, and the airplane pitched upward in response to the first officer's application of a substantial nose-up control correction. During this period, the vertical wind changed from a 40-fps downdraft to a 10-fps updraft. The reversal in wind component combined with a substantial nose-up pitch rate increased the angle of attack rapidly. At 1805:48, 3 seconds after TOGA was engaged, a +2.0 g vertical acceleration was recorded and the stickshaker probably again activated for about 1 second. At 1805:50, the airplane began to pitch down. During this time, the magnitude of the "fly-up" command presented by the command bars had decreased; however, they were still presenting a "fly-up" command when the airplane began to pitch down. The data contained in the performance analysis and the flight director study do not permit the Safety Board to conclude that the first officer was "flying the command bars" during the short time that the TOGA Mode was engaged. The data suggest that, in response to the stickshaker, the first officer ignored the command bars and applied nose-down control to silence the stickshaker. The data also show that when the stickshaker activated, the airplane's pitch attitude was 6° nose-up, the airspeed was about 150 KIAS, and the airplane was accelerating. Consequently, had the first officer been able to match the airplane's pitch attitude with the command bar position, the airplane might have cleared the ground. The shallow tire marks in the soft ground about 1 mile before the runway 17L threshold indicates a rather mild touchdown and additional evidence that the airplane's descent had almost been arrested. However, because of the uncertainties in the dynamic wind analysis, and in further recognition of the turbulent environment affecting the flightcrew, the Safety Board cannot conclude that other pilots would have been able to avoid ground contact. The Safety Board believes, however, that avoidance of ground contact could only have been assured positively if the missed approach had been executed when the captain perceived the first indications of a microburst wind shear, when the airplane was between 700 and 800 feet AGL.

Regardless of the first officer's response to the command bars, the flight director's TOGA mode did not provide optimum pitch command guidance for penetrating wind shears. In this instance, 1.25 Vs was about 131 KIAS and stickshaker activation speed was about 111 to 113 KIAS. The TOGA logic was designed to maintain 1.25 Vs and, therefore, would present pitch command guidance that would sacrifice altitude to maintain 131 KIAS, even though that airspeed was well above stickshaker activation airspeeds. The sacrifice of altitude to maintain airspeed is contrary to present wind shear penetration doctrines and, in this instance, it sacrificed the climb performance which was available down to and at stickshaker speed. The Safety Board notes that other air carriers have cautioned against the use of the TOGA mode during takeoff and go-arounds during wind shear encounters; however, the Delta L-1011 POM provided no guidance regarding the limitations of the flight director system TOGA mode under such circumstances.

In conclusion, at 1748, Cell "D" did not exist. Within the next 12 minutes, the cell was born, grew to a VIP level 4 weather echo, and its growth to a VIP level 4 weather echo occurred beyond the geographical confines of the DFW Airport's LLWAS. The Safety Board believes that the storm cell's rapid development made it virtually impossible for routine weather observation and reporting procedures to transmit an accurate and timely description of the cell to the air traffic controllers and, in turn, to flight 191.

The facts and circumstances of the accident also showed that the controllers in the DFW ATCT were not aware of the severity of the weather contained in Cell "D." The microburst touched the ground about 9,000 feet beyond the closest LLWAS sensor and its divergent winds did not place the LLWAS into alarm until after the accident. In addition, the DFW ATCT did not have available the type of radars which could depict either the intensity of the precipitation or the speed of movement of the air within Cell "D." Therefore, while the controllers were able to locate the cell on their ASR-7 radar, they were not able to describe to flight 191 the severity of the weather associated with the cell. The Safety Board will not speculate as to what effect this corroborative information would have had on the course of events, but with the additional information on which to base his decision, the captain may have decided to make alternate action. Therefore, the Safety Board concludes that the limitations in the airport weather surveillance that precluded the controllers from detecting the severity of the weather on the final approach contributed to the accident.

Although the Safety Board concluded that the airplane's powerplants had neither failed nor malfunctioned, the positions of the components of the engine reverser systems on the airplane's engines showed that the captain or first officer had selected reverse thrust at or immediately after the airplane first touched down. However, given the fact that the positions of the engine reverser components also indicated that forward thrust had been commanded on the No. 2 and No. 3 engines while reverse thrust was still commanded on the No. 1 engine, the Safety Board concludes that forward thrust was selected on all three engines either simultaneous with, or immediately after, the No. 1 engine separated from the airplane. The Safety Board cannot determine whether the selection of forward thrust was a deliberate flightcrew action or whether one of the pilots had his hand on the reverse thrust levers and his hand was driven forward by the impact forces. Regardless of how it occurred, given the time of the occurrence and the facts and circumstances of the impact and postimpact sequence, the Safety Board concludes that the selection and withdrawal of reverse thrust on the engines did not contribute either to the accident or to the severity of the impact.

2.5 Occupant Survival

Fire entered the left side of the mid-cabin between the time the No. 1 engine struck the automobile on State Highway 114 and the time that it struck the south water tank. The airplane's ground speed was over 200 knots when it struck the south water tank. The impact destroyed the forward and mid-cabin sections and simultaneously ignited a large fire which enveloped the airplane. The impact caused the rear cabin and empennage to separate from the remainder of the fuselage between seat rows 33 and 34 and this section came to rest on its left side over 1,000 feet beyond the water tank. The separation caused massive disruption of the rear cabin from row 33 aft to row 40.

The mid-cabin forward of the separation was destroyed by impact forces and fire. Only eight passengers who were seated between rows 21 and 33 survived. All survivors suffered blunt force trauma; seven of the eight sustained burns in addition to blunt force trauma.

Another four persons, including a flight attendant, seated between the separation and row 40 survived. These persons occupied seats in the area of the rear cabin which had been damaged heavily in addition to the massive disruption of surrounding cabin structure. The Safety Board considers the survival of the 12 persons seated forward of row 40 most fortuitous inasmuch as 7 of them were burned and all were seated in portions of the cabin that had been subjected to the high-impact forces which destroyed seats and surrounding structure. Based on these facts, the Safety Board concludes that the impact sequence was not survivable for persons seated forward of row 40.

Except for the destroyed missing left cabin wall, the rear cabin between rows 40 and 46 was relatively intact. The six persons in this section who were killed had been seated along the missing left cabin wall. The surviving 14 passengers and 2 flight attendants had occupied seats located predominately in the center and right side of the cabin. The Safety Board concludes that the impact sequence was survivable for persons seated aft of row 40 and who occupied the center and right row of seats.

Except for one flight attendant and three passengers, all of the survivors escaped unaided from the rear cabin. Although the survivors' escape was greatly hampered because the cabin was lying on its left side and because they were covered with fuel and had fuel in their eyes, their ability to escape was facilitated because there was little disruption of the seats and furnishings in the center and right side of the cabin, there was adequate illumination inside and outside the cabin, and there was no fire. Had fire occurred within the aft cabin area, either in-flight, before the separation occurred, or on the ground with the cabin section lying on its left side, there surely would have been few if any survivors.

The Safety Board also tried to determine whether the survival possibilities of flight 191's occupants would have been enhanced had the airplane not struck the water tanks. At the time of the accident, two large fully fueled cargo airplanes--a McDonnell Douglas DC-8 and DC-10--and a Boeing 747 tail maintenance stand were located on a service ramp south-southeast of the water tanks. Had flight 191 missed the water tanks, it could have either struck these two airplanes and the maintenance stand or continued along the ground. Had flight 191 struck the two airplanes and the maintenance stand, the impact sequence and ensuing fire would have been equally or even more catastrophic than it was. Had flight 191 avoided the water tanks and the service ramp, the survival possibilities for its passengers probably would have been equally as bad or worse than those which existed in the actual impact sequence. Flight 191 was traversing unpaved ground at a ground speed in excess of 200 knots, its nose landing gear had separated, it was on fire and the fire had penetrated into the passenger cabin, and it was already breaking up as a result of impacting the automobile and several highway light standards. There is little doubt that the airplane would have continued to break apart and exacerbate the existing fire as it continued across the airport surface. Given these two scenarios, the Safety Board believes that a catastrophic and probably unsurvivable environment would have ensued regardless of whether flight 191 struck the airplanes and maintenance stand on the service ramp or avoided the service ramp and continued along the airport surface.

With regard to the flight attendant jumpseats' damaged seatbelts and shoulder harnesses, the testing showed that, although they had been manufactured in 1982, the damage had decreased their tensile strength significantly. Despite the fact that there are no procedures or guidelines to aid airline maintenance and inspector personnel in determining at what point the condition of the belts and harnesses require replacement, the severe and obviously long-standing damage clearly indicated that they should have been replaced in accordance with accepted airline maintenance practices. The incorrect installation of the restraint systems on the R-4 and L-4 flight attendant jumpseats would not have affected their performance; however, the fact that these defects were not discovered during the airplane's various maintenance inspections leads the Safety Board to believe that the airline's inspection procedures were less than adequate.

Emergency Response.--The DFW Airport's DPS personnel responded quickly and efficiently and contributed significantly to saving the lives of a number of seriously injured victims. The Safety Board believes that much of the effectiveness of the emergency response was due to the immediate availability of the airport's paramedic and EMT personnel.

However, the Safety Board's investigation disclosed several problem areas which, under other accident circumstances, could affect adversely the medical treatment and survival of accident victims at the airport. Forty-five minutes was required to complete the notification of off-airport agencies whose assistance might have been needed for lifesaving activities. The Safety Board believes that this was an excessive amount of time and that the DFW Airport Emergency Plan's communications procedures should be improved to provide for more efficient and timely notification of the mutual aid agencies.

The Safety Board also believes that had more persons with serious injuries survived, the lack of coordination with area hospitals could have decreased the ability of these hospitals to treat properly the number of types of casualties involved. Therefore, the improvements to the emergency plan should include procedures to provide timely information to those hospitals selected to receive casualties. The National Fire Protection Association (NFPA) recently issued guidance material on this subject. Chapter 3, Section 6.5 of NFPA 424M, Manual for Airport/Community Planning states:

> The plan should designate a medical transportation officer whose responsibilities include:
>
> (a) Alerting hospitals and medical personnel of the emergency.
>
> (b) Directing transportation of casualties to hospitals.
>
> (c) Accounting for casualties by recording route of transportation, hospitals transported to, and casualty's name and extent of injuries.
>
> (d) Advising hospitals when casualties are en route.
>
> (e) Maintaining contact with hospitals, medical transportation, the senior medical officer, on-scene command post and the command post.

The Safety Board believes that the guidance material cited above should serve as a guideline for plans and procedures to coordinate the transportation of casualties from the accident scene to selected hospitals.

Disaster Preparedness.--The Safety Board recognizes that communications and coordination problems are likely to occur during any large emergency response effort involving multiple jurisdictions; however, thorough planning, training, and periodic full-scale drills can reduce such problems appreciably. The Safety Board believes that periodic tests of the DFW Airport Emergency Plan's communications procedures would have disclosed that the required notifications of off-airport agencies could not be completed within a reasonable timeframe, and that the system for alerting off-airport ambulances and hospitals was incomplete. These discrepancies, once identified, could have been corrected. Therefore, the Safety Board has forwarded recommendations to the FAA urging that these exercises be developed and conducted.

At the time of this accident, 6 years had elapsed since the last full-scale exercise of the DFW Airport Emergency Plan. This interval was excessive and most probably contributed to the difficulties experienced by the DPS personnel with off-airport notification procedures and with procedures in the assembly area for off-airport units.

The Safety Board has long believed that full-scale tests of emergency plans and procedures should be conducted periodically at certificated airports. As a result of its study of airport certification and operations, 27/ the Safety Board recommended on April 16, 1984, that the FAA:

> Amend 14 CFR 139.55 to require a full-scale demonstration of certificated airport emergency plans and procedures at least once every 2 years, and to require annual validation of notification arrangements and coordination agreements with participating parties. (A-84-34)

27/ Safety Study--"Airport Certification and Operations" (NTSB/SS-84/02).

On August 6, 1984, the FAA replied that it intended to revise 14 CFR Part 139 to require full-scale demonstration of emergency plans and procedures where practicable and that the required timing will be "variable from 2 to 4 years based on the air carrier activity level at each airport." On October 23, 1985, the FAA issued Notice of Proposed Rule Making (NPRM) No. 85-22 containing proposed amendments to 14 CFR Part 139; however, the NPRM did not contain requirements for periodic demonstrations of certificated airport emergency plans and procedures. The Safety Board now deems the FAA's response to the recommendation unsatisfactory and reiterates Safety Recommendation A-84-34, which has been classified as "Open—Unacceptable Action."

3. CONCLUSIONS

3.1 Findings

1. Between 1752 and 1800, the Cell "D" radar weather echo positioned off the north end of the DFW Airport intensified from a VIP level 1 to a VIP level 4.

2. The absence of the CWSU meteorologist from his station between 1725 and 1810, and the failure of CWSU procedures to require the position to be monitored by a qualified person during his absence precluded detection of the intensification of the weather echo north of the DFW Airport.

3. During its final approach to runway 17L, flight 191 flew into a very strong weather echo (VIP level 4) located north of the field. The weather echo contained a thunderstorm with a heavy rainshower.

4. The thunderstorm produced an outflow containing a microburst. The microburst touched down just north of the DFW Airport. The center of the microburst was 12,000 feet (1.97 nmi) north of the approach end of runway 17L and about 1,000 feet west of the extended centerline of the runway and the ground track of flight 191.

5. The microburst diameter was 3.4 kilometers. The horizontal wind shear across the microburst was at least 73 knots, and the maximum updraft and downdraft were 25 fps (4.8 knots) and 49 fps (29 knots), respectively.

6. There were six distinct reversals of vertical wind components along the southern side of the microburst. The presence of this type of wind flow showed that vortices had formed along the boundary between the descending air and the ambient environment.

7. Flight 191 penetrated the microburst and the vortex flow in the southern side of the microburst.

8. The first officer successfully transited the first part of the microburst encounter by rotating the airplane above a 15° nose-up pitch attitude and by increasing engine thrust to almost takeoff power.

9. About 1805:35, 17 seconds before initial impact, the airplane encountered rapid reversals in the lateral, horizontal, and vertical winds causing the stickshaker to activate. The first officer exerted a 20- to 25-pound push force on the control column in response to the stickshaker.

10. The flight director was placed in TOGA mode during the initiation of a missed approach 7 seconds before initial touchdown. The flight director's TOGA mode does not command the optimum pitch attitudes required to transit a low-altitude wind shear. However, the Safety Board could not determine whether the first officer was following the pitch commands provided by the flight director's TOGA mode during the final 7 seconds of the flight.

11. The first officer exerted a 20- to 25-pound pull force on the control column in order to avoid ground contact. The stickshaker activated momentarily, and the first officer relaxed the pull force on the control column, which made ground contact inevitable.

12. Delta 191 touched down softly and almost avoided ground contact.

13. The ATC controller's speed adjustment procedures were not causal to the accident.

14. The 3 nmi separation standard was not maintained between flight 191 and the preceding Learjet. The loss of separation did not contribute to the accident.

15. The Feeder East and Arrival Radar-1 controllers provided flight 191 with all weather information that was available to them.

16. Several flightcrews saw lightning in the rain shower just north of the airport; however, they did not report what they saw to the ATC controllers.

17. The LCE controller observed lightning about or shortly after the time flight 191 entered the microburst windfield. Therefore, the failure of the LCE controller to report it to flight 191 was not a causal factor.

18. The flightcrew and the captain had sufficient information to assess the weather north of the approach end of runway 17L. The lightning observed and reported by the first officer was adequate, combined with the other data known to the flightcrew and captain, to determine that there was a thunderstorm between the airplane and the airport.

19. The north side of the cell formation containing the thunderstorm was not masked from flight 191 by any intervening clouds.

20. The captain's decision to continue beneath the thunderstorm did not comply with Delta's weather avoidance procedures; however, the avoidance procedures did not address specifically thunderstorm avoidance in the airport terminal area.

21. After penetrating the first part of the microburst, the engine thrust which had been increased was then reduced and at 550 feet AGL the airplane had restabilized momentarily on the glide slope. The captain evidently believed that they had successfully flown through the worst of the microburst wind shear, and the approach was continued.

22. The company had not provided guidance to its flightcrews concerning specific limits on the excursions of airplane performance and control parameters during low-altitude wind shear encounters that would dictate the execution of a missed approach.

23. Although the captain did not audibly express his decision to execute a missed approach until he called for the selection of the "TOGA" mode on the flight director 7 seconds before initial impact, maximum engine thrust had been applied before the airplane's rapid departure below the glideslope.

24. The accident was not survivable for persons seated forward of row 40 although 8 persons seated forward of the row survived. The accident was survivable for persons located aft of row 40 and seated in the center and right row of seats.

25. Despite notification and coordination difficulties, the emergency response of the DPS personnel and equipment to the accident scene was timely and effective and contributed significantly to saving the lives of a number of the survivors.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable causes of the accident were the flightcrew's decision to initiate and continue the approach into a cumulonimbus cloud which they observed to contain visible lightning; the lack of specific guidelines, procedures, and training for avoiding and escaping from low-altitude wind shear; and the lack of definitive, real-time wind shear hazard information. This resulted in the aircraft's encounter at low altitude with a microburst-induced, severe wind shear from a rapidly developing thunderstorm located on the final approach course.

4. RECOMMENDATIONS

4.1 Recommendations Addressing Low-Altitude Wind Shear and Weather

This section will discuss previous Safety Board activities and recommendations relevant to the low-altitude wind shear hazard.

Since 1970, the Safety Board has identified low-altitude wind shear as a cause or contributing factor in 18 accidents involving transport category airplanes. Eleven of these accidents were nonfatal, but the other 7 resulted in the loss of 575 lives. Six of the fatal accidents and at least eight of the nonfatal accidents occurred after the airplanes encountered the convective downburst or microburst winds associated with thunderstorms or heavy rainshowers.

The accidents attributed to convective wind shear have occurred during landing approach, attempted go-around, and takeoff phases of flight. One fatal accident occurred during a landing when the airplane encountered a wind shear caused by a feature of the surrounding terrain--the wind shear was cited as a contributing factor. The other two accidents, both nonfatal, occurred after the airplanes passed through frontal system boundaries during the landing approach.

One of the frontal system wind shear encounters involved an Iberian Airlines DC-10 with 167 persons aboard which struck the approach light piers and seawall embankment during an ILS approach at Boston Logan International Airport on December 17, 1973. 28/ The airplane was damaged substantially when the landing gear sheared off, and there were serious injuries during crew and passenger evacuation. It could have been a catastrophic accident.

The findings about wind shear in this accident investigation first prompted the Safety Board to recommend that the FAA require that wind shear be included in pilot training programs and that the development of wind shear detection systems be expedited.

The crash of an Eastern Air Lines B-727 at John F. Kennedy International Airport, Jamaica, New York, on June 24, 1975, killed 113 persons. 29/ That accident occurred when the airplane encountered on final approach the outflowing winds and downdraft associated with thunderstorms. The airplane experienced a rapid loss of airspeed and developed a high descent rate from which it did not recover. Following the investigation of the accident, the Safety Board issued 14 safety recommendations which addressed the development of both ground-based and airborne equipment for detecting wind shear, the determination of operational limitations for various types of aircraft, the enhancement of airborne vertical guidance equipment, and reiterated the need for enhanced pilot training programs.

Acknowledging the serious hazard presented by wind shear encounters, the FAA and other government and industry organizations began extensive research and development programs which were in general consonance with actions recommended by the Safety Board. The occurrence of three more air carrier accidents between 1975 and 1977 30/ which were attributed to encounters with wind shear placed more emphasis on the research and development efforts. Several positive actions resulted: pilot training programs were enhanced to increase flightcrew awareness of the hazard; operational techniques were evaluated in simulation; and various technologies for both ground-based and airborne wind shear detection and monitoring equipment were evaluated.

Unfortunately, tangible benefits from the research and development of the past 10 years have yet to be realized. The only operational wind shear detection system thus far is the LLWAS, an anemometer array around the airport which will alert the tower controller to shifting ground-level winds. The limitations of the system were acknowledged from the beginning and it never has been regarded as other than an interim measure until more sophisticated equipment is developed.

28/ Aircraft Accident Report--"Iberia Lineas Aereas de Espana (Iberian Airlines) McDonnell Douglas DC-10-30, EC CBN, Logan International Airport, Boston, Massachusetts, December 17, 1973" (NTSB/AAR-74/14).
29/ Aircraft Accident Report—"Eastern Air Lines, Inc., Boeing 727-225, John F. Kennedy International Airport, Jamaica, New York, June 24, 1975" (NTSB/AAR-76/08).
30/ Aircraft Accident Reports—"Continental Air Lines, Inc., Boeing 727-224, N88777, Stapleton International Airport, Denver, Colorado, August 7, 1975" (NTSB/AAR-76/14); "Allegheny Airlines, Inc., Douglas DC-9, N994VJ, Philadelphia, Pennsylvania, June 23, 1976" (NTSB/AAR-78/02); and "Continental Air Lines, Inc., Boeing 727-224, N32725, Tucson, Arizona, June 3, 1977" (NTSB/AAR-78/09).

The limitations of LLWAS as an operational decisionmaking aid to flightcrews were illustrated by the crash of a Pan American B-727 during takeoff from New Orleans Airport on July 9, 1982. 31/ Although the LLWAS indicated wind shear in the vicinity of the airport, there were no means to relate the information to the hazard presented to a particular takeoff. Consequently, the flightcrew of the accident aircraft failed to perceive the danger; 153 persons died when the flight encountered a classic microburst at or immediately after the point of takeoff.

The Safety Board again recommended actions to be taken by the FAA, several of which addressed the need to improve the current technology for systems so they could be used effectively for flightcrew operational decisions. Other recommendations addressed the use of the wealth of information gained from the JAWS program at the Denver Stapleton Airport to improve the LLWAS system and procedures for its use, to evaluate the potential of other technologies such as the microwave doppler radar for detecting wind shear, to develop better methods to communicate usable information to controllers and pilots for timely and accurate decisionmaking, and to provide better information for pilot training.

Primarily in response to congressional pressure, the FAA contracted with the National Academy of Sciences for a study of the wind shear hazard and measures for accident prevention. The Safety Board's staff supported the study by providing details of accident data and the rationale for the Board's safety recommendations. The committee's findings and recommendations issued in September 1983 were consistent with the Safety Board's views.

The Safety Board has issued a total of 36 Safety Recommendations to the FAA related to the aviation wind shear hazard. The recommendations are cited verbatim along with a summary of the FAA responses and the Safety Board-assigned status in appendix H.

The most significant recommendations were issued following the accidents at Boston Logan on December 17, 1973, at John F. Kennedy on June 24, 1975, at Philadelphia on June 23, 1976, and at New Orleans on July 9, 1982. Specifically, these recommendations addressed the needs for:

Wind shear forecasting to define better the conditions conducive to microburst development and to inform dispatchers and pilots when these conditions are present as well as when there is a wind shear potential involving nonfrontal systems.

Improved communications between the weather service, air traffic controllers, and pilots to ensure that pilots are provided the most current forecasts and existing conditions for planning flights, landing approaches, and departures.

Improved real-time detection of wind shear conditions by (1) use of the LLWAS to its maximum potential by ensuring optimum placement of the anemometer array and optimum software alarm logic, and (2) expeditious development and installation of microwave Doppler radar equipment at airports located in areas of high microburst risk.

31/ Aircraft Accident Report—"Pan American World Airways, Inc., Clipper 759, Boeing 727-235, N4737, New Orleans International Airport, Kenner, Louisiana, July 9, 1982" (NTSB/AAR-83/02).

Pilot training which stresses avoidance of wind shear and discusses the meteorological conditions conducive to the development of wind shears, particularly convective wind shears.

Pilot training programs which (1) discuss the aerodynamic performance problems associated with wind shear penetrations as well as simulations of wind shear encounters during all low-altitude phases of flight, (2) stress the need for rapid recognition and response by using all of the airplane's performance capability, and (3) address the effect of an out-of-trim speed condition on the control forces needed to use the airplane's performance.

Development, certification, and installation of airborne equipment which can provide the pilot early warning of wind shear encounters and optimize the logic of command guidance instruments to enhance the pilot's response to the encounter.

Cooperative efforts with the FAA and industry personnel in accident investigations and in followup of the Safety Board's recommendations spurred the initiation of several wind shear research and development projects in the late 1970s. These have included:

Development and implementation of the LLWAS.

Development of wind shear models which were distributed for use in engineering aircraft performance simulation as well as in pilot training applications.

Development of airborne instruments designed to enhance pilot response to inadvertent wind shear encounter and the adoption of standards for such instrumentation.

Distribution of an AC describing the wind shear hazard and preferable piloting procedures in the event of inadvertent encounters.

Evaluation of several technologies for the detection of a wind shear including acoustical Doppler, light detection and ranging, infrared radiometry, and microwave Doppler radar. Of these, microwave Doppler radar appears to offer the highest potential for consistent detection within the existing state-of-the-art.

Comprehensive study of the microburst phenomena and the use of microwave Doppler radar in the JAWS.

As a result of these FAA activities, 24 of the Safety Board's recommendations have been classified as "Closed--Acceptable or Acceptable Alternate Action." These include those recommendations for additional research of the hazard and those for the development and issuance of wind shear guidance material. The other 12 recommendations have been classified as "Open-Acceptable Action," pending further action by the FAA. These recommendations address the need for a more definitive and standardized flightcrew training program, the modification or enhancement of present terminal weather detection equipment, and the hardware implementation of new technology.

On April 14, 1986, the FAA circulated the draft of an Integrated Wind Shear Program Plan to interested government agencies and the aviation industry for review. This plan describes the FAA's ongoing efforts to:

- Develop an authoritative flightcrew training program for airline training departments, including operational procedures, classroom curricula, written manuals, video presentations, and simulator exercises.

- Develop improved sensors for the surface detection of low-altitude wind shears, including an enhanced LLWAS, NEXRAD, and airport Terminal Doppler Weather Radar (TDWR).

- Develop sensors for airborne detection of wind shear, using microwave Doppler, laser, or infrared radiometer technology.

All of these programs are currently under contract for development, and working groups have been established to develop warning threshold criteria and standardized communication terminology.

The FAA program addresses nearly all of the actions proposed in the Safety Recommendations issued by the Safety Board since 1973 and includes the milestone schedules for the implementation of actions that have been proven to be technically feasible. However, the Safety Board is concerned that one most important--and difficult--problem is not being adequately addressed for the present and is not specifically addressed in the FAA's current programs: the communication of hazardous weather information available from ground sensors to the flightcrew in time for the information to be useful in go/no-go decisionmaking. Current procedures to relay NWS information through the ATC system are not and will never be adequate for dynamic weather conditions. However, actions can be taken to improve these procedures.

Specifically, the Safety Board believes that additional NWS information should be transmitted on ATIS broadcasts. Other critical meteorological information must also be made immediately available to the local controller. Therefore, the Safety Board advocates that the FAA assign a qualified person to each major terminal facility to perform this function. The person should be a meteorologist and should function as do meteorologists in the CWSUs of the ARTCCs.

Although the Safety Board supports the FAA's program plan to implement the much needed TDWR, it believes that a concurrent effort is needed to evaluate the existing radars with lesser, but certainly useful, capabilities for expedited use at busy terminals. With TDWR installation, these "lesser" radars would eventually be transferred to airports not receiving the TDWRs. Existing weather radars which provide reflectivity levels and turbulence—but not definitive wind—information could be used by a terminal weather coordinator to augment LLWAS for detection of heavy rain and possible wind shear in the airport vicinity. Further, the FAA's new ATC radars (ASR-9) have weather channel capability.

Thus, as a result of this accident investigation and a review of the FAA's ongoing activities, the Safety Board issued the following additional recommendations to the FAA:

> Issue an Air Carrier Operations Bulletin to direct Principal Operations Inspectors to require air carriers operating under 14 CFR Part 121 to record in pilot training records the specific wind shear simulator training administered to pilots during initial and recurrent training sessions. (Class II, Priority Action) (A-86-65)

> Issue an Air Carrier Operations Bulletin to direct Principal Operations Inspectors to review those sections of company operations manuals and training curricula pertaining to thunderstorm avoidance procedures to verify that flightcrews clearly understand the policy that no aircraft should attempt to land or take off if its flight path is through, under, or near (within a minimum specified distance) a thunderstorm. (Class II, Priority Action) (A-86-66)

> Issue an Air Carrier Operations Bulletin to direct Principal Operations Inspectors to require that company operations manuals and training curricula caution pilots not to use flight director systems during an inadvertent wind shear encounter unless such systems incorporate wind shear logic. (Class II, Priority Action) (A-86-67)

> Include a message on the Automatic Terminal Information Service broadcast whenever weather conditions conducive to thunderstorm or microburst development exist in the terminal area or when such actual conditions have been observed or reported. (Class II, Priority Action) (A-86-68)

> Amend Federal Aviation Administration Handbook 7210.3G, Facility Operation and Administration, to require the observation of lightning or existence of cumulonimbus and towering cumulus clouds as items to be included on Automatic Terminal Information Service broadcasts when that information has been included in the remarks section of official weather reports. (Class II, Priority Action) (A-86-69)

> Require tower controllers to issue thunderstorm, microburst, and wind shear reports when conditions differ from Automatic Terminal Information Service broadcast information and when actual pilot reports (PIREPS) have been received, and to solicit further PIREPS until such time that confirmation is received that the condition no longer exists. (Class II, Priority Action) (A-86-70)

> Develop a position in major terminal facilities, to be staffed with National Weather Service meteorologists or Federal Aviation Administration personnel trained for meteorological observations, to be the focal point for weather information coordination during periods of convective weather activity that adversely affects aircraft and air traffic control system operations. (Class II, Priority Action) (A-86-71)

Require that all personnel engaged in weather coordinator duties attend the formal Weather Coordinator Training Course offered by the Federal Aviation Administration Academy, and expand that course to include training in the interpretation of weather echo intensity levels as depicted on remote weather radar displays. (Class II, Priority Action) (A-86-72)

Develop a thorough convective weather refresher course as part of recurring training for all personnel actively engaged in the control of air traffic. (Class II, Priority Action) (A-86-73)

Issue a General Notice to all en route and terminal facilities emphasizing the phraseology requirements for describing weather areas as stated in Federal Aviation Administration Handbook 7110.65D. (Class II, Priority Action) (A-86-74)

Conduct, during the current convective season, an operational test of currently available weather radar systems at selected airports and, based on the results of the evaluation, consider deployment of a system or systems to supplement data derived from the Low Level Wind Shear Alert System as an interim measure until deployment of advanced Doppler radar in terminal areas. (Class II, Priority Action) (A-86-75)

The Safety Board also issued the following recommendations jointly to the Federal Aviation Administration and the National Weather Service:

Develop procedures to require that Center Weather Service Units are attended constantly during operation so that information concerning hazardous weather conditions, such as thunderstorms, wind shear, icing, and turbulence, either occurring or expected to occur, receives prompt, appropriate dissemination. (Class II, Priority Action) (A-86-76)

Develop procedures to require the Center Weather Service Unit meteorologist to disseminate information on rapidly developing hazardous weather conditions, such as thunderstorms and low-altitude wind shear, to Federal Aviation Administration Terminal Radar Approach Control and/or tower facilities immediately upon detection of the conditions. (Class II, Priority Action) (A-86-77)

Expedite the implementation of equipment to upgrade all Center Weather Service Units to the state of the technology in data acquisition and display capability. (Class II, Priority Action) (A-86-78)

The Safety Board also issued the following recommendations to the National Oceanic and Atmospheric Administration:

Require that pertinent information and formal training programs derived from microburst and convective storm research be provided in a timely manner to operational meteorologists. (Class II, Priority Action) (A-86-79)

Require that all offices that have a weather radar display or displays and an aviation weather warning responsibility to airports have those airports clearly located on a useable map on each weather radar display. (Class II, Priority Action) (A-86-80)

Develop definitive aviation weather warning criteria based on radar weather echo intensities and the proximities of radar weather echos to airport approach and departure corridors, and implement a means to communicate this information immediately to Federal Aviation Administration Terminal Radar Approach Control and tower facilities. (Class II, Priority Action) (A-86-81)

4.2 Other Recommendations

Two safety problems not related to the low-altitude wind shear hazard were evident in the investigation of this accident. Both of these problems are serious in that they can directly affect the survival of persons involved in an aircraft accident.

The first problem involved the restraint systems at the airplane's flight attendant jumpseats. The shoulder harnesses and seatbelts were badly worn and were, in some cases, improperly installed. To correct the deficiencies, the Safety Board recommended that the Federal Aviation Administration:

Issue an Advisory Circular with guidance on the limits of wear and damage to restraint system webbing material that would necessitate the replacement of worn or damaged webbing. (Class II, Priority Action) (A-86-82)

Review, and require improvements as necessary in, Delta Air Lines quality control program regarding inspection and replacement of restraint systems. (Class II, Priority Action) (A-86-83)

Issue a maintenance alert bulletin that cites the problems of the flight attendant restraint system discovered following the Delta L-1011 accident at Dallas/Fort Worth International Airport, Texas, on August 2, 1985, and require Principal Maintenance Inspectors to emphasize to air carriers the requirements and guidance for periodic inspections of flight attendant restraint systems for worn and damaged webbing, improper installation, and worn shoulder harness guides. (Class II, Priority Action) (A-86-84)

Issue an Airworthiness Directive to correct the design deficiency of Heath Techna jumpseats (Part No. MPD 241100) that permit the seatbelt webbing to chafe against the seatpan retraction spring. (Class II, Priority Action) (A-86-85)

Perform a Directed Safety Inspection of flight attendant restraint systems on air carrier aircraft to determine design deficiencies that cause damage to webbing materials, and establish a program as needed to replace worn or damaged webbing and correct design deficiencies. (Class II, Priority Action) (A-86-86)

The second problem involved the communications and coordination with off-airport medical units during the implementation of the Dallas/Fort Worth Airport Emergency Plan after the accident. To correct the problem, the Safety Board sent a letter to the executive director of the airport which recommended that the airport board:

> Revise its disaster response notification procedures to provide for timely and effective notification of mutual-aid agencies whose assistance is needed. (Class II, Priority Action) (A-86-87)
>
> Revise its procedures for coordinating with area hospitals during mass casualty disasters to provide the hospitals with timely information regarding estimated numbers of victims, injury categories, destinations, and arrival times. (Class II, Priority Action (A-86-88)
>
> Conduct full-scale demonstrations of the Dallas/Fort Worth Airport Emergency Plan and Procedures every 2 years. (Class II, Priority Action) (A-86-89)

In addition, the Safety Board believes that full-scale tests of emergency plans and procedures should be conducted periodically at certificated airports. As a result of its study of airport certification and operations, the Safety Board recommended that the Federal Aviation Administration:

> Amend 14 CFR 139.55 to require a full-scale demonstration of certificated airport emergency plans and procedures at least once every 2 years, and to require annual validation of notification arrangements and coordination agreements with participating parties. (A-84-34)

On August 6, 1984, the FAA replied that it intended to revise 14 CFR Part 139 to require full-scale demonstration of emergency plans and procedures where practicable and that the required timing will be "variable from 2 to 4 years based on the air carrier activity level at each airport." On October 23, 1985, the FAA issued NPRM No. 85-22 containing proposed amendments to 14 CFR Part 139; however, the NPRM did not contain requirements for periodic demonstrations of certificated airport emergency plans and procedures. The Safety Board now deems the FAA's response to the recommendation unsatisfactory and reiterates Safety Recommendation A-84-34, which has been classified as "Open—Unacceptable Action."

The Safety Board also recommended that the Federal Aviation Administration:

> Develop guidelines for use by Airport Certification Inspectors to determine the timeliness and effectiveness of emergency notification procedures at certificated airports. (Class II, Priority Action) (A-86-90)
>
> Require Airport Certification Inspectors to conduct communications tests in accordance with Federal Aviation Administration guidelines for emergency plan notification procedures of mutual-aid agencies as part of the annual airport certification inspection and to evaluate the timeliness and effectiveness of those notification procedures. (Class II, Priority Action) (A-86-91)

The Safety Board also recommended that the American Association of Airport Executives and the Airport Operators Council International:

> Advise its members of the circumstances of the emergency response to the accident at Dallas/Fort Worth International Airport, Texas, on August 2, 1985, and urge them to reevaluate their own plans and procedures to identify any similar strengths and weaknesses. (Class II, Priority Action) (A-86-92)
>
> Urge its members who operate 14 CFR Part 139 certificated airports to conduct full-scale demonstrations of airport emergency plans and procedures every 2 years. (Class II, Priority Action) (A-86-93)

The Safety Board also recommended that the National Fire Protection Association:

> Advise its Technical Committee on Aircraft Rescue and Firefighting of the circumstances of the emergency response to the accident at Dallas/Fort Worth International Airport, Texas, on August 2, 1985. (Class II, Priority Action) (A-86-94)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JIM BURNETT
Chairman

/s/ PATRICIA A. GOLDMAN
Vice Chairman

/s/ JOHN K. LAUBER
Member

/s/ JOSEPH T. NALL
Member

August 15, 1986

5. APPENDIXES

APPENDIX A

INVESTIGATION AND PUBLIC HEARING

1. **Investigation**

The National Transportation Safety Board was notified of the accident about 1930 eastern daylight time on August 2, 1985, and immediately dispatched an investigative team to the scene from its Washington, D.C. headquarters. Investigative groups were formed for operations, air traffic control, witnesses, meteorology, survival factors, structures, powerplants, airplane systems, digital flight data recorder, maintenance records, cockpit voice recorder, airplane performance, human performance, and airport emergency response.

Parties to the investigation were the Federal Aviation Administration, Delta Air Lines, the Air Line Pilots Association, the Lockheed California Company, the Dallas/Fort Worth Airport, Rolls Royce Ltd., the National Weather Service, the Federal Bureau of Investigation, and the Airport Operators Council International.

2. **Public Hearing**

A 4-day public hearing was held in Irving, Texas, beginning October 29, 1985. Parties represented at the hearing were the Federal Aviation Administration, Delta Air Lines, the Air Line Pilots Association, the Lockheed California Company, the Professional Flight Controllers Association, and the National Weather Service.

One deposition was taken on December 12, 1985.

APPENDIX B

PERSONNEL INFORMATION

Captain Connors

Captain Edward N. Connors, 57, was employed by Delta Air Lines on June 14, 1954. He held Airline Transport Certificate No. 122502 with an airplane multiengine land rating and commercial privileges in airplane single-engine land. He was type rated in McDonnell Douglas DC-3, -6, -7, and -8; Fairchild F-27; Vickers Viscount VC-700 and 800; Boeing 727; and Lockheed L-1011. His last first-class medical certificate was issued February 19, 1985, and he was required to possess correcting glasses for near vision while exercising the privileges of his airman's certificate.

Captain Connors qualified as captain in the Lockheed L-1011 on October 26, 1979. He passed his last proficiency check on September 17, 1984, passed his last line check on September 7, 1984, and completed recurrency training on September 16, 1984. The captain had flown 29,300 hours, 3,000 of which were in the Lockheed L-1011. During the last 90 days, 30 days, and 24 hours the captain had flown 166 hours, 81 hours, and 5 hours, respectively. The captain had been off duty 16 hours 5 minutes before reporting for duty on August 2, 1985. At the time of the accident the captain had been on duty 4 hours 54 minutes, 3 hours 54 minutes of which were flight time.

First Officer Price

First Officer Rudolph P. Price, Jr., 42, was employed by Delta Air Lines on February 13, 1970. He held Commercial Pilot Certificate No. 1942059 with airplane multiengine and single-engine land ratings and an instrument rating. His last first-class medical certificate was issued February 22, 1985, with no waivers or limitations.

First Officer Price qualified initially in the Lockheed L-1011 in January 1981, but was assigned to fly other equipment. He requalified as a Lockheed L-1011 first officer on March 14, 1984. He passed his last proficiency check on April 25 and completed recurrency training on April 24, 1985. The first officer had flown 6,500 hours, 1,200 of which were in the Lockheed L-1011. During the last 90 days, 30 days, and 24 hours he had flown 150 hours, 38 hours, and 5 hours, respectively. At the time of the accident the first officer's rest time before reporting for this flight and his duty times on the day of the flight were the same as the captain's.

Second Officer Nassick

Second Officer N. Nassick, 43, was employed by Delta Air Lines on October 19, 1976. He held Flight Engineer Certificate No. 170327500 with a turbojet engine power airplane rating. His first-class medical certificate was issued September 24, 1984, with no waivers or limitations. Pursuant to 14 CFR 63.3(a) a flight engineer need only have a second-class medical certificate. A first-class medical certificate is valid for 12 months for those operations requiring only a second-class medical certificate.

Second Officer Nassick qualified as second officer in the Lockheed L-1011 on April 7, 1980. He passed his last proficiency check on March 7, 1985, and completed recurrency training on March 6, 1985. The second officer had flown 6,500 hours, 4,500 hours of which were in the Lockheed L-1011. During the last 90 days, 30 days, and

24 hours he had flown 161 hours, 34 hours, and 5 hours, respectively. At the time of the accident the second officer's rest time before reporting for this flight and his duty time on the day of the flight were the same as the captain's

Flight Attendant Alford

Flight Attendant Frances Alford, 30, was employed by Delta Air Lines on January 31, 1977. The flight attendant had been assigned exit 1-L for takeoff and landing, and had completed recurrent emergency training on October 24, 1984.

Flight Attendant Amatulli

Flight Attendant Jenny Amatulli, 35, was employed by Delta Air Lines on January 30, 1970. The flight attendant had been assigned exit 4-L for takeoff and landing, and had completed recurrent emergency training on September 20, 1984.

Flight Attendant Artz

Flight Attendant Frieda Artz, 31, was employed by Delta Air Lines on November 20, 1972. The flight attendant had been assigned exit 3-L for takeoff and landing, and had completed recurrent emergency training on October 24, 1984.

Flight Attendant Chavis

Flight Attendant Vickie Chavis, 29, was employed by Delta Air Lines on June 4, 1979. The flight attendant had been assigned exit 3-R for takeoff and landing, and had completed recurrent training on January 31, 1985.

Flight Attendant Johnson

Flight Attendant Diane Johnson, 29, was employed by Delta Air Lines on July 3, 1978. The flight attendant had been assigned exit 2-R for takeoff and landing, and had completed recurrent emergency training on January 15, 1985.

Flight Attendant Lee

Flight Attendant Virginia Lee, 31, was employed by Delta Air Lines on July 3, 1978. The flight attendant had been assigned exit 1-R for takeoff and landing, and had completed recurrent emergency training on January 10, 1985.

Flight Attendant Modzelewski

Flight Attendant Joan Modzelewski, 33, was employed by Delta Air Lines on September 17, 1973. The flight attendant had been assigned exit 2-L for takeoff and landing, and had completed recurrent emergency training on October 10, 1984.

Flight Attendant Robinson

Flight Attendant Wendy Robinson, 23, was employed by Delta Air Lines on January 3, 1985. The flight attendant had been assigned exit 4-R for takeoff and landing, and had completed her most recent emergency training during her initial training.

Feeder East Controller Hubbert

Feeder East Controller Robert S. Hubbert, 46, was employed by the Federal Aviation Administration on June 6, 1968, and entered on duty at the Dallas/Fort Worth Airport TRACON on July 19, 1971. The controller's last second-class medical certificate was issued on October 12, 1984. He is a full performance level controller and is qualified to perform radar air traffic control functions at the TRACON.

Radar Arrival-1 Controller Wayson

Radar Arrival-1 Controller Thomas R. Wayson, 29, was employed by the Federal Aviation Administration at the Dallas/Fort Worth Airport TRACON on August 23, 1981. His last second-class medical certificate was issued on May 14, 1985, with no waivers or limitations. He is a full performance level controller and performs radar air traffic control duties at the TRACON.

Local Control East Controller Skipworth

Local Control East Controller Gene D. Skipworth, 47, was employed by the Federal Aviation Administration on August 8, 1968, and transferred to the Dallas/Fort Worth Airport TRACON on October 19, 1971. His last second-class medical certificate was issued on September 11, 1984, with no waivers or limitations. He is an Area Supervisor and also performs a full range of controller duties in the radar room and tower cab.

APPENDIX C

AIRPLANE INFORMATION

Lockheed L-1011-385-1, N726DA

The airplane, manufacturer's serial No. 193C1163, was delivered to Delta Air Lines on February 28, 1979, and had been operated by the airline continuously since that date. A review of the airplane's maintenance records and flight logs showed that all applicable Airworthiness Directives had been complied with, and that all checks and inspections were completed within their specified time limits. The records review showed that the airplane had been maintained in accordance with company procedures and Federal Aviation Administration rules and regulations and disclosed no discrepancies that could have affected adversely the performance of the airplane or any of its components.

The airplane was powered by three Rolls Royce RB 211 22B engines rated at 41,030 pounds static takeoff thrust at sea level with a 5-minute time limit.

The following is pertinent statistical data:

Airplane

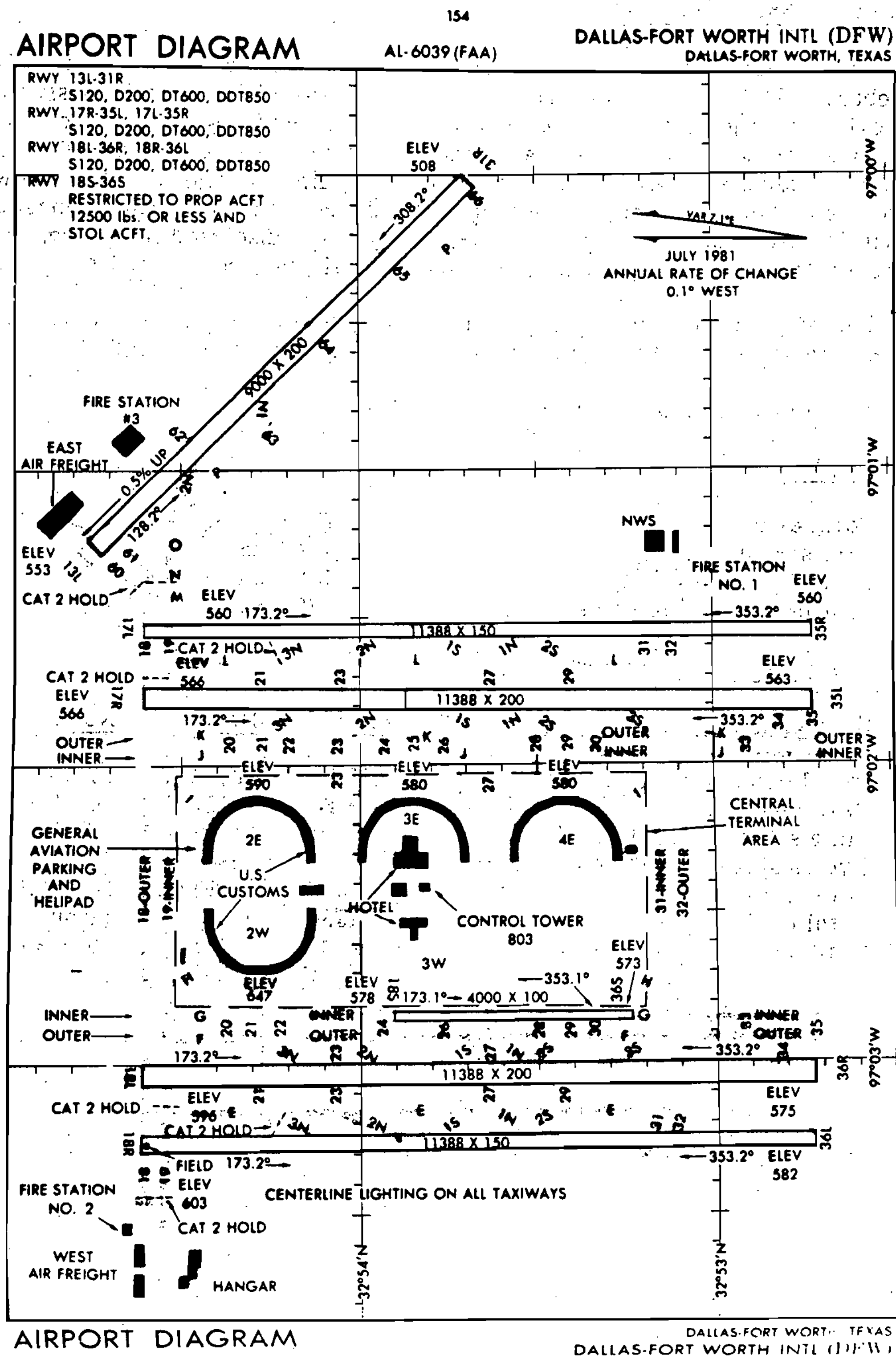
Total airplane time	20,555 hours
Last service check	7/27/85
Last "C" check	5/25/85
Last heavy maintenance visit	5/25/85

Powerplants

Engine	No. 1	No. 2	No. 3
Serial number	10391	10514	10478
Date installed	7/12/85	4/22/85	10/23/83
Time since installation	167	711.6	5,269.3
Cycles since installation	88	354	2,766
Total time	28,103.3	15,828.2	26,756.5
Total cycles	16,538	8,489	15,501
Date out of last shop visit	5/14/85	4/2/85	10/3/83

APPENDIX D

DALLAS FORT WORTH INTERNATIONAL AIRPORT DIAGRAM



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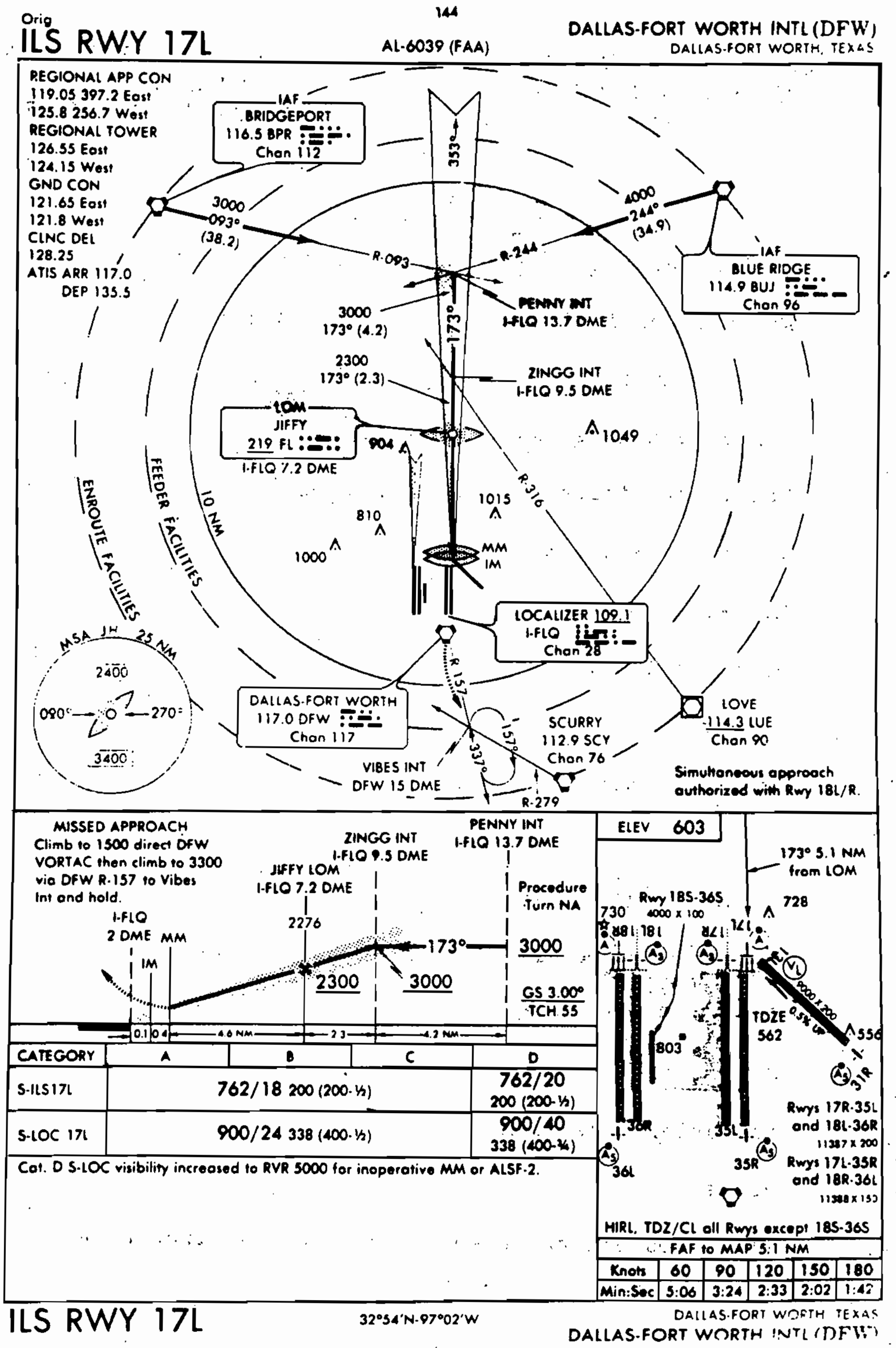
APPENDIX E

RUNWAY 17L
INSTRUMENT LANDING SYSTEM (ILS) APPROACH CHART



"ILLUSTRATION ONLY - NOT TO BE USED FOR NAVIGATIONAL PURPOSES"

APPENDIX F

COCKPIT VOICE RECORDER TRANSCRIPT

TRANSCRIPT OF A FAIRCHILD A-100 COCKPIT VOICE RECORDER, S/N 2911 REMOVED FROM THE DELTA AIRLINES L1011 WHICH WAS INVOLVED IN AN ACCIDENT AT DALLAS-FT. WORTH INTERNATIONAL AIRPORT ON AUGUST 2, 1985

LEGEND

CAM	Cockpit area microphone voice or sound source
RDO	Radio transmission from accident aircraft
-1	Voice identified as Captain
-2	Voice identified as First Officer
-3	Voice identified as Flight Engineer
-?	Voice unidentified
XXX	Miscellaneous aircraft
APP	Approach Control
CTR	Center
GPWS	Ground Proximity Warning System
UNK	Unknown
*	Unintelligible word
#	Nonpertinent word
%	Break in continuity
( )	Questionable text
(( ))	Editorial insertion
---	Pause
Note:	All times are expressed in central daylight time.

INTRA-COCKPIT TIME & SOURCE	INTRA-COCKPIT CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	AIR-GROUND COMMUNICATIONS CONTENT
17:35:15 CAM-2	We might not have time, how much of a layover time do we have there?		
CAM-?	About an hour		
CAM-2	Supposed to be two hours?		
CAM-?	Fifty minutes		
17:35:26 CAM-2	We're gonna eat up a lot of that time		
			((ATIS received by flight engineer))
			Listen DFW arrival information romeo, two one four seven Greenwich, weather six thousand scattered, two one thousand scattered, visibility one zero, temperature one zero one, dew point six seven, wind calm, altimeter two niner niner two, runway one eight right one seven left, visual approaches in progress, advise approach control that you have romeo
		17:35:33 CTR	Delta one ninety one cleared direct Blue Ridge Blue Ridge nine arrival descend and maintain flight level two five zero
CAM-?	* * *		
		17:35:39 RDO-1	Okay Delta one ninety one direct Blue Ridge cleared Blue Ridge arrival, we're outta twenty nine for two five zero

INTRA-COCKPIT

TIME & SOURCE	CONTENT
CAM-1	Right
17:35:59 CAM-?	((Sound of female voice))
CAM-?	(More than) an hour's hold out there
17:36:38 CAM-2	You're back on this for a while?
17:36:39 CAM-3	I think
17:36:47 CAM-?	Another exciting day in the life of
17:37:40 CAM-?	Eighty nine * * *
17:37:45 CAM-?	He said * * * yeah

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:35:46 CTR	Delta one ninety one verify you are at two five zero knots now
17:35:51 RDO-1	You right
17:35:53 CTR	Okay
RDO	%

INTRA-COCKPIT TIME & SOURCE	CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	CONTENT
CAM-1	You did day something to the people	RDO	%
CAM-3	Yeah		
17:39:00 CAM-2	That's a nice feature we have on this airplane that we don't have on the seven six, I flew that for a while		
17:39:05 CAM-3	Control wheel steering on the seven six does your altitude engage like we have it		
17:39:13 CAM-2	If you're in control wheel steering, control wheel steering will not hold altitude		
CAM-?	* * *		
		17:39:17 CTR	Delta one ninety one heavy, descend and maintain flight level two four zero
		17:39:23 RDO-1	Delta one ninety one well continue to two four zero
17:39:26 CAM-1	This airplane you roll in thirty degrees of bank and let it go, it will maintain altitude to * * *		

INTRA-COCKPIT		AIR-GROUND COMMUNICATIONS	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
17:39:45 CAM-2	The seven six has other advantages --- a nice big screen * *		
		17:39:49 CTR	One ninety one heavy, contact Fort Worth Center one two seven point six
		17:39:55 RDO-1	Delta one ninety, one ninety one one seven six, thank you all for the help
		17:39:58 CTR	You're welcome, sir good day, thanks
		RDO	%
17:40:03 CAM-1	* * *		
17:40:06 CAM-2	It's a nice airplane to * *		
17:40:10 CAM-2	Really, the cockpit's great		
17:40:11 CAM-1	To ride in		
17:40:13 CAM-2	Oh to ride in, sure * *		

INTRA-COCKPIT		AIR-GROUND COMMUNICATIONS	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
17:40:20 CAM-2	I don't think I've ever been in the back of it		
CAM-1	I've been in it several times, I think * * *		
		17:40:21 RDO-1	Fort Worth Delta one ninety one with you outta twenty four and a half for twenty four
		17:40:26 CTR	Delta one ninety one Fort Worth Center roger
17:40:33 CAM-1	I hope I never have to fly it		
17:40:36 CAM-2	Well you shouldn't have to		
CAM-2	You'd get spoiled if you did		
17:40:45 CAM-1	Not me * * *		
CAM-3	The seven six would spoil you?		
17:41:10 CAM-2	A * * not up to date either		

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:41:16 CAM-1	The seven six and seven five are getting a bunch of em
17:41:20 CAM-2	The seven five and seven six both
CAM-?	* * popular to
17:41:30 CAM-?	Yeah * *

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:41:19 963	Delta nine sixty three I'd like to deviate to the south
17:41:22 CTR	Plane wanting deviation south Delta nine sixty three, turn right heading of two six zero to intercept the Blue Ridge zero one zero radial inbound
17:41:31 963	We're not going to be able to do that sir that's right in the middle of a big thunderstorm up here and we need to either stay on present heading or deviate slightly south and east of course

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:42:05 CAM-1	What are you doing now
17:42:07 CAM-2	Trying to remember how to get to the hold page, how do you get to the hold page
17:42:10 CAM-1	You have to set the altitude in first
17:42:13 CAM-2	Oh I know how I see what happens I thought I had it in
CAM-?	* * * hold
17:42:36 CAM-2	He want us at two five zero
17:42:42 CAM-1	Oh I thought you were cutting it * * * throttle * * * two fifty
17:43:24 CAM-2	It would be nice if we could deviate to the south of two five zero

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:41:40 CTR	Delta nine sixty three, I got an area twelve miles wide all the aircraft are going through there, good ride, I'll have a turn back in before you get to the weather

INTRA-COCKPIT TIME & SOURCE	CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	CONTENT
17:43:27 CAM-1	Somebody just ahead of us tried to and they wouldn't let them do it		
17:43:30 CAM-1	They're working a twelve mile corridor		
CAM-1	The airplanes that have been going through there have been all right * * *		
		17:43:33 CTR	Delta one ninety one descend and maintain one zero thousand, the altimeter two niner niner one
17:43:39 GAM-3	Think that might of been for us guys		
		17:43:42 RDO-1	I'm sorry was that for Delta one ninety one
		17:43:45 CTR	One niner one descend and maintain one zero thousand, the altimeter two niner niner one and suggest now a heading of two five zero two five zero to join the Blue Ridge zero one zero radial and inbound, we have a good area there to go through
		17:43:56 RDO-1	Well, I'm looking at a cell at about heading of ah two five five and it's a pretty good size cell and I'd rather not go through it, I'd rather go around it one way or the other

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:44:33 CAM-2	He must be going to turn us before we get to that area
CAM-1	Put the girls down
CAM	((Sound of chime))
CAM-1	* * *

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:44:06 CTR	I can't take you south, I gotta line of departures to the south, I've had about sixty aircraft go through this area out here ten to twelve miles wide there getting a good ride, no problems
17:44:16 RDO-1	We'll I see a cell now about heading two four zero
CTR	Okay head ((overlaying transmission)) when I can I'll turn you into Blue Ridge, it'll be about the zero one zero radial
RDO	%
17:45:21 AMR	We're going to hold you to that

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:45:34 CAM-2	Did he just give us a vector, did he say intercept
17:45:35 CAM-1	Two five zero
17:45:36 CAM-3	Yeah
CAM-2	We got an intercept coming?
17:45:39 CAM-3	Intercept the Blue Ridge
17:45:41 CAM-1	We're on the Blue Ridge though aren't we?
17:45:45 CAM-2	Are we on the Blue Ridge arrival * * intercept * * flaps four
17:45:51 CAM-1	I guess he's going to turn us (down)

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:45:23 RDO-1	You ain't the only one
RDO	%

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:46:16 CAM-1	It might help you to get down to ten quicker
CAM-2	I can't though
CAM-1	Yeah, you can use the spoilers --- speed brakes
CAM-2	Okay
17:46:26 CAM-2	You haven't seen the * *

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:46:45 RDO-1	Center Delta one ninety one, are you gonna turn us on the Blue Ridge arrival pretty quick?
17:46:50 CTR	Delta one ninety one, you can proceed direct Blue Ridge now and the Blue Ridge nine arrival cross Baton at and maintain niner thousand
17:46:57 RDO-1	Okay direct Blue Ridge, Blue Ridge arrival cross Baton at nine thousand thank you sir

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:47:11 CAM-1	He's sleeping, get him out of bed
17:47:30 CAM-3	What do you need?

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:47:05 CTR	American five thirty nine as soon as the weather will permit, you can now proceed direct Blue Ridge, Blue Ridge nine arrival cross Baton at and maintain niner thousand
17:47:12 A539	Okay, we're gone, Blue Ridge at nine
17:47:15 CTR	Roger
17:47:17 A539	Baton at nine
17:47:19 CTR	Baton at nine
17:47:21 1896	* eighteen ninety six descend and maintain seven thousand
17:47:27 1896	Eighteen ninety six departing nine for seven
17:47:30 CTR	One two six romeo, turn right heading of two six five

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:47:36 CAM-3	What do you need?
17:47:38 CAM-2	The altimeter * *
17:47:39 CAM-3	Nine one's the altimeter he gave us, nine two you got, okay I * *
17:47:42 CAM-3	Warning panel
17:47:43 CAM-2	Check
17:47:45 CAM-3	Altimeters
CAM-?	* *
CAM-3	Shoulder harness

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:47:36 126R	Negative sir not at this time, we've got weather
17:47:41 CTR	Okay, maintain your present heading then
17:47:43 126R	Six romeo
17:47:46 CTR	Hey can you --- would you like to go down to (Scurry)

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:47:51 CAM-3	Landing lights
17:48:04 CAM-3	What was that?
17:48:05 CAM-1	This guys
17:48:06 CAM-1	Getting kinda hot in the oven with this controller, see that's what the lack of experience does

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:47:52 126R	I'll tell you what we'll just cancel and get out of your hair
17:47:54 CTR	Okay, one two six romeo IFR cancelled ah, squawk one two zero zero
17:48:05 D233	Delta two thirty three with you descending to twenty four
17:48:09 CTR	Delta two thirty three Fort Worth Center roger

Amended October 2, 1985

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:48:22 CAM	((Sound of autopilot disconnect))
17:49:29 CAM-1	You're in good shape, I'm glad we didn't have to go through that mess I thought sure he was going to send us through it
CAM-1	* * ten *

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:48:15 CTR	Delta five fifty seven direct Blue Ridge, Blue Ridge nine arrival cross Baton at and maintain niner thousand
17:48:21 D557	Baton at nine and Blue Ridge at --- Delta five fifty seven
17:48:25 CTR	Roger
17:48:30 CTR	* eighteen ninety six, ah, disregard
17:48:49 CTR	* eighteen ninety six, descend and maintain six thousand, regional approach one two three point niner
17:48:55 1896	Twenty three niner down to six eighteen ninety six

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:51:19 CAM-3	Looks like its raining over Fort Worth
17:51:23 CAM-2	Yeah
17:51:28 CAM-?	* Dallas *

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:48:57 CTR	Delta nine sixty three, regional approach one one niner zero five
17:49:01 D963	Nineteen oh five, thanks for your help
17:51:03 CTR	Delta one ninety one, radio check
17:51:05 RDO-1	Loud and clear
17:51:42 CTR	Delta one ninety one heavy regional approach control one one niner zero five
17:51:46 RDO-1	One one nine zero five one niner one, you all have a nice evening, we appreciate the help

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:53:21 CAM	((Sound of altitude alert))
17:55:14 CAM	((Sound of altitude alert))

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:51:50 CTR	Good day
RDO	%
17:52:08 RDO-1	Regional approach Delta one ninety one heavy going through eleven with romeo
17:52:15 ARR	Delta one ninety one heavy fly heading two thirty five
17:52:16 RDO-1	Two thirty five heading
RDO	%
17:53:41 ARR	Delta one ninety one heavy descend to seven thousand
17:53:44 RDO-1	Delta one ninety one out of nine for seven
RDO	%

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:55:53 CAM-?	Ten degrees
17:55:58 CAM-2	Ten degrees flaps, please
17:56:00 CAM-1	Say again
17:56:01 CAM-2	Ten degrees flaps
17:56:13 CAM-2	Start the approach check
17:56:14 CAM-3	Continuous ignition
17:56:15 CAM-1	On
17:56:16 CAM-3	Seatbelts

Amended October 2, 1985

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:55:46 ARR	Delta one ninety one heavy turn ten degrees left, reduce speed to one eight zero
17:55:50 RDO-1	Delta one ninety one wilco

INTRA-COCKPIT TIME & SOURCE	CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	CONTENT
17:56:17 CAM-1	On		
17:56:18 CAM-3	Radio nav switches		
17:56:18 CAM-1	Radios		
17:56:19 CAM-3	Auto flight panels	17:56:19 ARR	Delta one ninety one as soon as speed is reduced, descend to five thousand
17:56:20 CAM-1	Correction on that		
		17:56:24 RDO-1	Delta one ninety one as soon as we slow to one ninety, go to five thousand wilco
		17:56:28 ARR	Attention, all aircraft listening except for Delta twelve ninety one is going to go across the airport, there's a little rainshower just north of the airport and their starting to make ILS approaches other than Delta twelve ninety one should tune up one oh nine one for one seven left
CAM-1	Say again the auto flight panels		

Amended October 2, 1985

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:56:51 CAM	((Sound of cockpit call chime))
17:57:04 CAM-1	Say again
17:57:05 CAM-3	Auto flight panels
17:57:06 CAM-1	Checked
17:57:07 CAM-3	VHF nav radios
17:57:08 CAM-1	Manual
17:57:09 CAM-3	Altimeter flight and nav instruments
CAM-1	Ah set and cross checked
17:57:12 CAM-3	The airspeed EPR bugs

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:57:00 RDO-1	One ninety one, out of seven for five
17:57:03 ARR	Okay one ninety one

Amended October 2, 1985

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:57:13 CAM-1	One thirty nine set and cross checked
17:57:16 CAM-3	Speed brake levers
17:57:17 CAM-1	Forward lights out
17:57:18 CAM-3	Flight attendants notified
17:57:19 CAM-3	Down to no smoking

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:57:45 RDO	((ILS tuned and identifier heard captain's side))
17:57:57 RDO-1	Delta twelve ninety one, we'd like to go around this buildup twelve o'clock to us can we turn left a little bit and go around the other side of it
17:58:03 ARR	Twelve ninety one twenty left or so is approved, call approach one twenty five eight

INTRA-COCKPIT TIME & SOURCE	INTRA-COCKPIT CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	AIR-GROUND COMMUNICATIONS CONTENT
		17:58:09 ARR	Delta one ninety one heavy, turn left heading one nine zero and I'll turn you right back on (down wind) in just a second
		17:58:14 RDO-1	Delta one ninety one understand heading one nine zero for now
		RDO	%
17:58:19 CAM	((Sound of altitude alert))		
17:58:41 CAM-?	All that screwing around (for nothing)		
		17:58:42 ARR	Delta one ninety one turn right two six zero
		17:58:44 RDO-1	Roger
17:58:48 CAM-?	All that screwing around * *		
17:59:07 CAM-3	Radio radio		
17:59:09 CAM-1	Radio		

Amended October 2, 1985

INTRA-COCKPIT

TIME & SOURCE	CONTENT
17:59:11 CAM-2	Radio
17:59:47 CAM-2	We're gonna get our airplane washed

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
17:59:37 ARR	Delta one ninety one turn right heading three four zero, contact approach one one nine four
17:59:42 RDO-1	Three four zero nineteen four so long, thanks for the help

Amended October 2, 1985

INTRA-COCKPIT		AIR-GROUND COMMUNICATIONS	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
17:59:50 CAM-1	What?		
17:59:51 CAM-2	We're gonna get our airplane washed		
		17:59:54 RDO-1	Approach Delta one ninety one with ya at five
		17:59:57 APP	One ninety one heavy expect one seven left
		17:59:59 RDO-2	Thank you sir
18:00:03 CAM-1	Identify both of them		
18:00:06 CAM-2	I didn't identify yours		
18:00:20 CAM	((Sound of static))		
CAM-1	Shut it off		

INTRA-COCKPIT

TIME & SOURCE	CONTENT

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:00:21 APP	Delta one ninety one heavy fly heading of three five zero
18:00:24 RDO-1	Roger
RDO	%
18:00:36 APP	American three fifty one, do you see the airport yet?
18:00:38 A351	As soon as we break out of this rain shower we will
18:00:40 APP	Okay three fifty one you're four from the marker join the localizer at or above two thousand three hundred cleared for ILS one seven left approach
18:00:46 A351	Cleared for the ILS American three fifty one
18:00:51 APP	One ninety one heavy reduce speed one seven zero turn left two seven zero
18:00:54 RDO-1	Roger

INTRA-COCKPIT

TIME & SOURCE	CONTENT

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:00:57 APP	Five juliot foxtrot turn left one nine zero
18:01:00 5JF	Left turn one nine zero
18:01:02 APP	Five juliot foxtrot increase your speed to one hundred and seventy knots, hold that to the marker, you're five miles from the marker, join the localizer at or above three thousand, cleared for an ILS one seven left approach
18:01:11 5JF	Cleared for the one seven left approach roger we're coming around to one nine zero
18:01:34 APP	Delta one ninety one heavy turn left to two four zero, descend and maintain three thousand
18:01:38 RDO-1	One ninety one, two four zero, outta five for three
18:01:40 APP	American three fifty one tower one two six five five
18:01:43 A351	So long

INTRA-COCKPIT TIME & SOURCE	INTRA-COCKPIT CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	AIR-GROUND COMMUNICATIONS CONTENT
		18:01:44 A539	American five thirty nine at five thousand turning right three one zero
		18:01:48 APP	American five thirty nine approach expect ILS one seven left
18:01:49 CAM	((Sound of gear warning horn))		
		18:01:50 A539	Okay
		18:01:52 APP	November five juliot foxtrot is four miles from the marker, maintain a speed of one seventy or better to the marker, you're cleared ILS one seven left, contact tower one two six five five
		18:02:01 5JF	One twenty six ninety five, good day
		18:02:04 APP	That's one two six point five five
		18:02:05 5JF	Twenty six fifty five good day
		18:02:08 APP	American five thirty nine descend and maintain three thousand

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:02:14 CAM-?	* * *

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:02:10 A539	Three thousand American five thirty nine
18:02:15 APP	Delta one ninety one heavy, traffic ten o'clock a mile northbound twenty four hundred unverified
18:02:18 RDO-1	Thank you
18:02:23 APP	American five thirty nine reduce speed one seven zero, caution wake turbulence you'll be following heavy Tristar
18:02:27 A539	One seventy on the speed American five thirty nine
18:02:35 APP	Delta one ninety one heavy is six miles from the marker, turn left heading one eight zero join the localizer at or above two thousand three hundred cleared for ILS one seven left approach
18:02:43 RDO-1	Delta one niner one roger, all that appreciate it

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:02:48 CAM	((Sound of gear warning horn begins five times due to airspeed oscillation about one hundred and eighty knots))
18:02:53 CAM	((Sound of gear warning horn ends))
18:03:08 CAM	((Sound of gear warning horn))
18:03:09 CAM-1	One six zero

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:02:46 D557	Regional approach Delta five fifty seven with you
18:02:49 APP	Delta five fifty seven approach fly heading two seven zero, expect ILS approach one seven left
18:02:55 D557	One seven zero for the left side Delta five fifty seven
18:03:03 APP	Delta one ninety one heavy, reduce your speed to one six zero please
18:03:06 RDO-1	Be glad to

INTRA-COCKPIT TIME & SOURCE	INTRA-COCKPIT CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	AIR-GROUND COMMUNICATIONS CONTENT
18:03:10 CAM-2	All right		
18:03:11 CAM-1	Localizer and glideslope captured		
18:03:12 CAM	((Sound of gear warning horn))		
		18:03:14 APP	American five thirty nine turn left two three zero
18:03:16 CAM-1	One six zero is your speed	18:03:16 A539	Two three zero American five thirty nine
		18:03:19 APP	Delta five fifty seven reduce speed to one seven zero
		18:03:22 D557	One seventy Delta five fifty seven
		18:03:31 APP	And we're getting some variable winds out there due to a sh- shower on short out there north end of DFW
		APP	American five thirty nine turn left to two two zero

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:03:34 CAM-?	Stuff is moving in * *
18:03:35 CAM-?	* *
18:03:36 CAM-?	* *
18:03:40 CAM	((Sound of gear warning and altitude chord))
18:03:43 CAM-1	One six zero's the speed

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:03:45 A539	Two two zero American five thirty nine
18:03:46 APP	Delta one ninety one heavy, reduce speed to one five zero, contact tower one two six five five
18:03:49 RDO-1	One two six five five, you have a nice day, we appreciate the help
18:03:52 APP	(Bye)
18:03:53 RDO-?	Five eighty six

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:04:07 CAM-2	Before landing check
18:04:08 CAM-3	Landing gear
18:04:10 CAM-1	Down, three green
18:04:11 CAM-3	Flaps slats
18:04:12 CAM-1	Thirty three, thirty three, green light
18:04:15 CAM-3	Fourteen green

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:03:58 RDO-1	Tower Delta one ninety one heavy, out here in the rain, feels good
18:04:01 TWR	Delta one ninety one heavy regional tower one seven left cleared to land, wind zero nine zero at five gusts to one five
18:04:06 RDO-1	Thank you, sir
18:04:10 TWR	American three fifty one, if you can make that next high speed there, pull up behind Delta and hold short of one seven right this frequency
18:04:15 A351	Three fifty one

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:04:18 CAM-2	Lightning coming out of that one
18:04:19 CAM-1	What?
18:04:21 CAM-2	Lightning coming out of that one
18:04:22 CAM-1	Where?
18:04:23 CAM-2	Right ahead of us
18:04:30 CAM-3	You get good legs don't ya
18:04:39 CAM-2	((Garbled comment overriden by radio))

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:04:29 RDO	((Sound of open microphone))
18:04:30 TWR	Delta ten sixty one cross one seven right without delay, ground point six five after you cross
18:04:36 D1061	Crossing seventeen right Delta ten sixty one
18:04:38 TWR	Three fifty one cross one seven right ground point six five after you cross

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:04:41 CAM-1	I don't have a DME on mine
18:04:43 CAM-2	I don't know, you haven't had it for the last five minutes
18:05:04 CAM-?	Wash that off a little bit
18:05:05 CAM-1	A thousand feet

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:04:45 TWR	Delta nine sixty three and American six nineteen cross one seen right ground point six five after you cross
18:04:51 A619	American six nineteen
18:04:52 D963	Nine six three roger
18:04:54 TWR	Three fifty one did you copy to cross
18:04:55 A351	Yes sir we're on the way American three fifty one
18:04:57 TWR	Thank you

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:05:08 CAM-1	Seven sixty two in the baro
18:05:12 CAM-1	I'll call 'em out for you
18:05:13 CAM-2	Aw right
18:05:19 CAM-1	Watch your speed
18:05:20 CAM	((Sound similar to rain begins and continues to impact))
18:05:21 CAM-1	You're gonna lose it all of a sudden, there it is
18:05:26 CAM-1	Push it up, push it way up

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:05:14 A178	You want American one seventy eight to turn the corner?
18:05:16 TWR	Yes sir, everybody around the corner when you're number one
18:05:20 TWR	American one fifty six contact departure, good day
18:05:22 A156	American one fifty six, so long

INTRA-COCKPIT		AIR-GROUND COMMUNICATIONS	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
18:05:27 CAM-1	Way up		
18:05:28 CAM-3	Way up		
18:05:29 CAM-1	Way up		
18:05:29 CAM	((Sound of engines high RPM))		
18:05:30 CAM-1	That's it		
		18:05:35 RDO	((Sound of microphone keying))
18:05:36 CAM-1	Hang on to the # #	18:05:36 TWR	American six twenty two cleared for takeoff
		18:05:38 A622	Cleared for takeoff American six twenty two
18:05:39 CAM-2	(What's vee ref?)		
		18:05:40 TWR	Five eight six into position one seven right

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:05:44 GPWS	Whoop whoop pull up
18:05:44 CAM	((Garbled sound))
18:05:45 CAM-1	Toga
18:05:46 CAM-?	* *
18:05:46 CAM	((Sound of radio altimeters))
18:05:46 GPWS	Whoop whoop pull up ((sound of GPWS is distributed evenly and continously))
18:05:47 CAM-?	Push it way up
18:05:48 GPWS	Whoop whoop pull up
18:05:49 GPWS	Whoop whoop pull up
18:05:52 CAM	((Sound of noise similar to landing; sound of takeoff warning horn. The sound continues for 1.6 seconds))

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:05:44 A586	Into position and hold five eighty six
18:05:46 TWR	November one five juliot fox can you make the ah we'll expedite down to the ah taxi thirty one and a right turn off the traffics a mile final

INTRA-COCKPIT

TIME & SOURCE	CONTENT
18:05:53.5 CAM-?	#
18:05:55.5 CAM-?	Oh # ((second impact))
18:05:58	((End of Recording))

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
18:05:53 N15JF	Juliot fox roger
18:05:56 TWR	Delta go around

APPENDIX G

FEDERAL AVIATION ADMINISTRATION ADVISORY CIRCULAR 00-50A JANUARY 23, 1979

AC 00-50A

DATE 1/23/79

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Washington, D.C.

Subject: LOW LEVEL WIND SHEAR

1. PURPOSE. This advisory circular is intended to provide guidance for recognizing the meteorological situations that produce the phenomenon widely known as low level wind shear. It describes both preflight and in-flight procedures for detecting and predicting this phenomenon as well as pilot techniques that minimize its effects when inadvertently encountered on takeoff or landing.

2. CANCELLATION. AC 00-50, dated April 8, 1976, is canceled.

3. BACKGROUND.

a. Wind shear is best described as a change in wind direction and/or speed in a very short distance in the atmosphere. Under certain conditions, the atmosphere is capable of producing some dramatic shears very close to the ground; for example, wind direction changes of 180 degrees and speed changes of 50 knots or more within 200 feet of the ground have been observed. It has been said that wind cannot affect an aircraft once it is flying except for drift and groundspeed. However, studies have shown that this is not true if the wind changes faster than the aircraft mass can be accelerated or decelerated.

b. The most prominent meteorological phenomena that cause significant low level wind shear problems are thunderstorms and certain frontal systems at or near the airport.

c. Appendix 1 contains a bibliography of FAA publications on wind shear.

Initiated by: AFS-220

4. METEOROLOGY.

a. Thunderstorms. The winds around a thunderstorm are complex (Figure 1). Wind shear can be found on all sides of a thunderstorm cell and in the downdraft directly under the cell. The wind shift line or gust front associated with thunderstorms can precede the actual storm by 15 nautical miles or more. Consequently, if a thunderstorm is near an airport of intended takeoff or landing, low level wind shear hazards may exist.

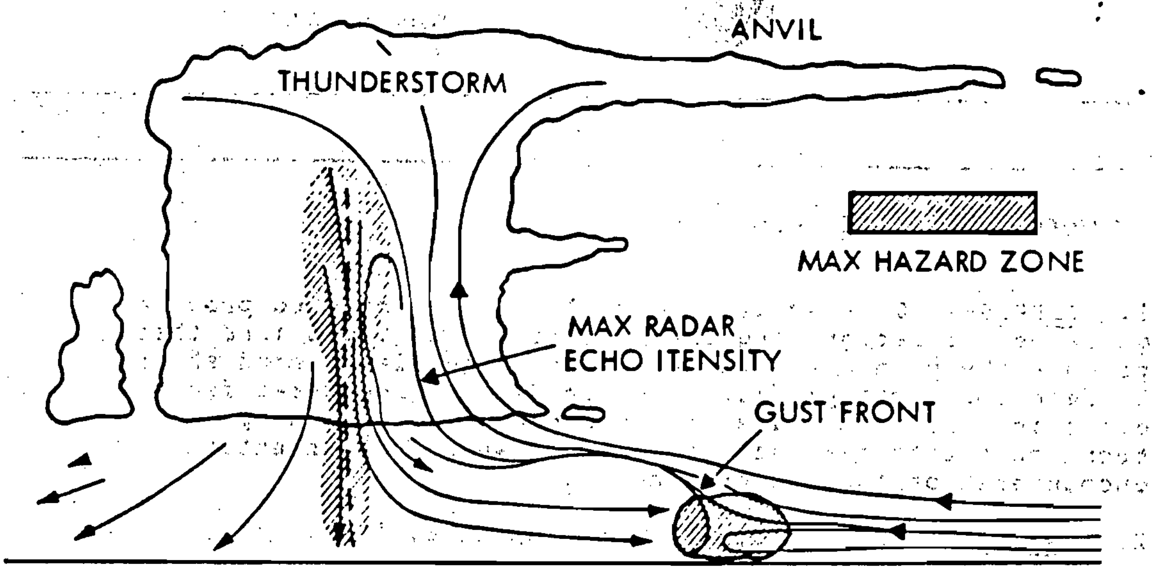


FIGURE 1. THUNDERSTORM HAZARD ZONES

b. Fronts. The winds can be significantly different in the two air masses which meet to form a front. While the direction of the winds above and below a front can be accurately determined, existing procedures do not provide precise, current measurements of the height of the front above the airport. The following is a method for determining the approximate height of the wind shear associated with a front.

(1) Wind shear occurs with a cold front just after the front passes the airport and for a short period thereafter. If the front is moving 30 knots or more, the frontal surface will usually be 5,000 feet above the airport about three hours after the frontal passage.

(2) With a warm front, the most critical period is before the front passes the airport. Warm front shear may exist below 5,000 feet for approximately six hours. The problem ceases to exist after the front passes the airport. Data compiled on wind shear indicates that the amount of shear in warm fronts is much greater than that found in cold fronts.

(3) Turbulence may or may not exist in wind shear conditions. If the surface wind under the front is strong and gusty, there will be some turbulence associated with wind shear.

c. Strong Surface Winds. The combination of strong winds and small hills or large buildings that lie upwind of the approach or departure path can produce localized areas of shear. Observing the local terrain and requesting pilot reports of conditions near the runway are the best means for anticipating wind shear from this source. This type of shear can be particularly hazardous to light airplanes.

d. Sea Breeze Fronts. The presence of large bodies of water can create local airflows due to the differences in temperature between the land and water. Changes in wind velocity and direction can occur in relatively short distances in the vicinity of airports situated near large lakes, bays or oceans.

e. Mountain Waves. These weather phenomena often create low level wind shear at airports that lie downwind of the wave. Altocumulus standing lenticular (ACSL) clouds usually depict the presence of mountain waves, and they are clues that shear should be anticipated.

5. DETECTING WIND SHEAR. Airplanes may not be capable of safely penetrating all intensities of low level wind shear. Pilots should, therefore, learn to detect, predict, and avoid severe wind shear conditions. Severe wind shear does not strike without warning. It can be detected by the following methods:

a. Analyze the weather during preflight.

(1) If thunderstorms are observed or forecast at or near the airport, be alert for the possibility of wind shear in the departure or arrival areas.

(2) Check the surface weather charts for frontal activity. Determine the surface temperature difference immediately across the front and the speed at which the front is moving. A 10° F [5° C] or greater temperature differential, and/or a frontal speed of 30 knots or more, is an indication of the possible existence of significant low level wind shear.

b. Be aware of pilot reports (PIREPS) of wind shear. Part 1 of the Airman's Information Manual recommends that pilots report any wind shear encounter to Air Traffic Control. This report should be in specific terms and include the loss/gain of airspeed due to the shear and the altitude(s) at which it was encountered. For example: "Denver tower, Cessna 1234 encountered wind shear, loss of 20 knots at 400 feet." This simple report is extremely important so that the pilot of the next airplane in sequence can determine the safety of transiting the same location. Reported shear that causes airspeed losses in excess of 15 to 20 knots should be avoided. Reported shears associated with a thunderstorm should also be avoided due to the speed which some storms move across the ground. The storm movement can cause one aircraft to encounter an airspeed increase which may appear harmless where the next aircraft can encounter a severe airspeed loss.

c. Assume that severe wind shear is present when the following conditions exist in combination.

(1) Extreme variations in wind velocity and direction in a relatively short time span.

(2) Evidence of a gust front such as blowing dust on the airport surface.

(3) Surface temperature in excess of 80°F.

(4) Dew point spread of 40°F or more.

(5) Virga (precipitation that falls from the bases of high altitude cumulus clouds but evaporates before reaching the ground).

d. Examine the approach or takeoff area with the airplane's radar set to determine if thunderstorm cells are in the vicinity of the airport. A departure or approach should not be flown through or under a thunderstorm cell.

e. Use the airplane instruments to detect wind shear.

(1) Pilots flying airplanes equipped with inertial navigation system (INS) should compare the winds at the initial approach altitude (1500-2000' above ground level (AGL)) with the reported runway surface winds to see if there is a wind shear situation between the airplane and the runway.

(2) If frontal activity does exist, note the surface wind direction to determine the location of the front with respect to the airport. If the airplane will traverse the front, compare the surface wind direction and speed with the wind direction and speed above the front to determine the potential wind shear during climbout or approach.

(3) Pilots flying airplanes equipped with a device which reads out groundspeed should compare the airplane's groundspeed with its airspeed. Any rapid changes in the relationship between airspeed and groundspeed represents a wind shear. Some operators have adopted the procedure of not allowing their aircraft to slow below a precomputed minimum groundspeed on approach. The minimum is computed by subtracting the surface headwind component from the true airspeed on approach.

(4) Pilots flying airplanes which do not have INS or groundspeed readouts should closely monitor their airplane's performance when wind shear is suspected. When the rate of descent on an ILS approach differs from the nominal values for the aircraft, the pilot should beware of a potential wind shear situation. Since rate of descent on the glide slope is directly related to groundspeed, a high descent rate would indicate a strong tailwind; conversely, a low descent rate denotes a strong headwind. The power needed to hold the glide slope also will be different from typical, no-shear conditions. Less power than normal will be needed to maintain the glide slope when a tailwind is present and more power is needed for a strong headwind. Aircraft pitch attitude is also an important indicator. A pitch attitude which is higher than normal is a good indicator of a strong headwind and vice versa. By observing the aircraft's approach parameters - rate of descent, power, and pitch attitude - the pilot can obtain a feel for the wind he is encountering. Being aware of the wind-correction angle needed to keep the localizer needle centered provides the pilot with an indication of wind direction. Comparing wind direction and velocity at the initial phases of the approach with the reported surface winds provides an excellent clue to the presence of shear before the phenomenon is actually encountered.

f. Utilize the Low Level Wind Shear Alert System (LLWSAS) at airports where it is available. LLWSAS consists of five or six anemometers around the periphery of the airport, which have their readouts automatically compared with the center field anemometer. If a wind vector difference of 15 knots or more exists between the center field anemometer and any peripheral anemometer, the tower will let the pilot know the winds from both locations. The pilot then may assess the potential for wind shear. An example of a severe wind shear alert would be the following: "Center field wind is 230 degrees at 7 knots; wind at the north end of Runway 35 is 180 degrees at 60 knots." In this case, a pilot departing on runway 35 would be taking off into an increasing tailwind condition that would result in significant losses of airspeed and, consequently, altitude.

6. AIRPLANE PERFORMANCE IN WIND SHEAR. The following information provides a basis for understanding the operational procedures recommended in this circular.

a. Power Compensation. Serious consequences may result on an approach when wind shear is encountered close to the ground after power adjustments have been already made to compensate for wind. Figures 2 and 3 illustrate the situations when power is applied or reduced to compensate for the change in aircraft performance caused by wind shear.

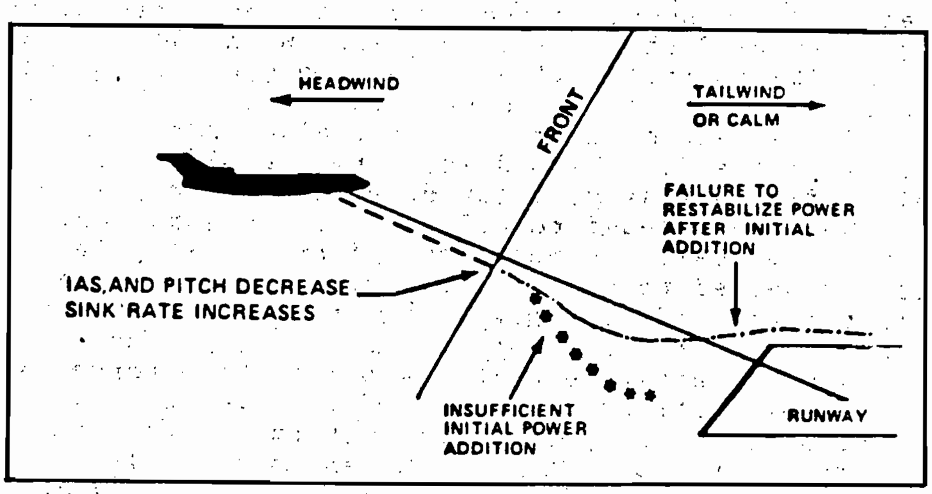


FIGURE 2. HEADWIND SHEARING TO TAILWIND OR CALM

(1) Consider an aircraft flying a 3° ILS on a stabilized approach at 140 knots indicated airspeed (IAS) with a 20-knot headwind. Assume that the aircraft encounters an instantaneous wind shear where the 20-knot headwind shears away completely. At that instant, several things will happen; the airspeed will drop from 140 to 120 knots, the nose will begin to pitch down, and the aircraft will begin to drop below the glide slope. The aircraft will then be both slow and low in a "power deficient" state. The pilot may then pull the nose up to a point even higher than before the shear in an effort to recapture the glide slope. This will aggravate the airspeed situation even further until the pilot advances the throttles and sufficient time elapses at the higher power setting for the engines to replenish the power deficiency. If the aircraft reaches the ground before the power deficiency is corrected, the landing will be short, slow, and hard. However, if there is sufficient time to regain the proper airspeed and glide slope before reaching the ground,

then the "double reverse" problem arises. This is because the throttles are set too high for a stabilized approach in a no-wind condition. So, as soon as the power deficiency is replenished, the throttles should be pulled back even further than they were before the shear (because power required for a 3° ILS in no wind is less than for a 20-knot headwind). If the pilot does not quickly retard the throttles, the aircraft will soon have an excess of power; i.e., it will be high and fast and may not be able to stop in the available runway length (Figure 2).

(2) When on approach in a tailwind condition that shears into a calm wind or headwind, the reverse of the previous statements is true. Initially, the IAS and pitch will increase and the aircraft will balloon above the glide slope. Power should initially be reduced to correct this condition or the approach may be high and fast with a danger of overshooting. However, after the initial power reduction is made and the aircraft is back on speed and glide slope, the "double reverse" again comes into play. An appropriate power increase will be necessary to restabilize in the headwind. If this power increase is not accomplished promptly, a high sink rate can develop and the landing may be short and hard (Figure 3). The double reverse problem arises primarily in downdraft and frontal passage shears. Other shears may require a consistent correction throughout the shear.

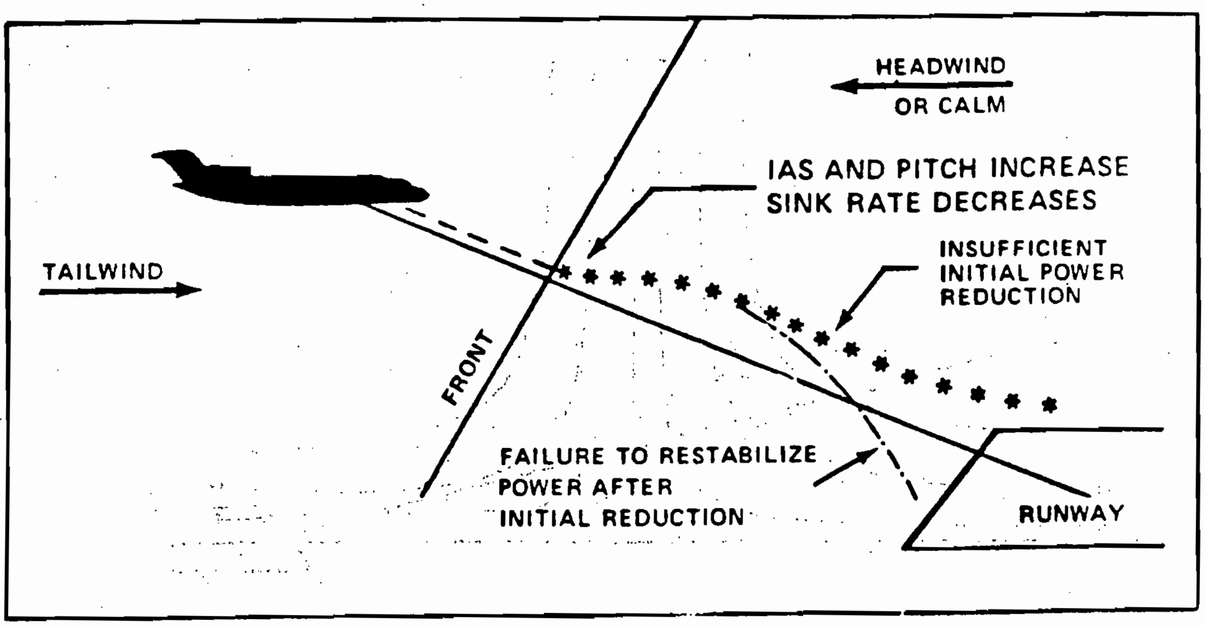


FIGURE 3. TAILWIND SHEARING TO HEADWIND OR CALM

(3) The classic thunderstorm "downburst cell" accident is illustrated in Figure 4. There is a strong downdraft in the center of the cell. There is often heavy rain in this vertical flow of air. As the vertical air flow nears the ground it turns 90 degrees and becomes a strong horizontal wind, flowing radially outward from the center. Point A in Figure 4 represents an aircraft which has not entered the cell's flow field. The aircraft is on speed and on glide slope. At Point B the aircraft encounters an increasing headwind. Its airspeed increases, and it balloons above the glide slope. Heavy rain may begin shortly. At Point C the "moment of truth" occurs. If the pilot does not fully appreciate the situation, he may attempt to regain the glide slope and lose excess airspeed by reducing power and pushing the nose down. Then in the short span of time between Points C and D the headwind ceases, a strong downdraft is entered and a tailwind begins increasing. The engines spool down, the airspeed drops below V_{ref}, and the sink rate becomes excessive. A missed approach initiated from this condition may not be successful. Note that a missed approach initiated at Point C (or sooner) would probably be successful since the aircraft is fast and high at this point. Note also that the pilot of an aircraft equipped with a groundspeed readout would see the telltale signs of a downburst cell shortly after Point B; i.e., rapidly increasing airspeed with decreasing groundspeed.

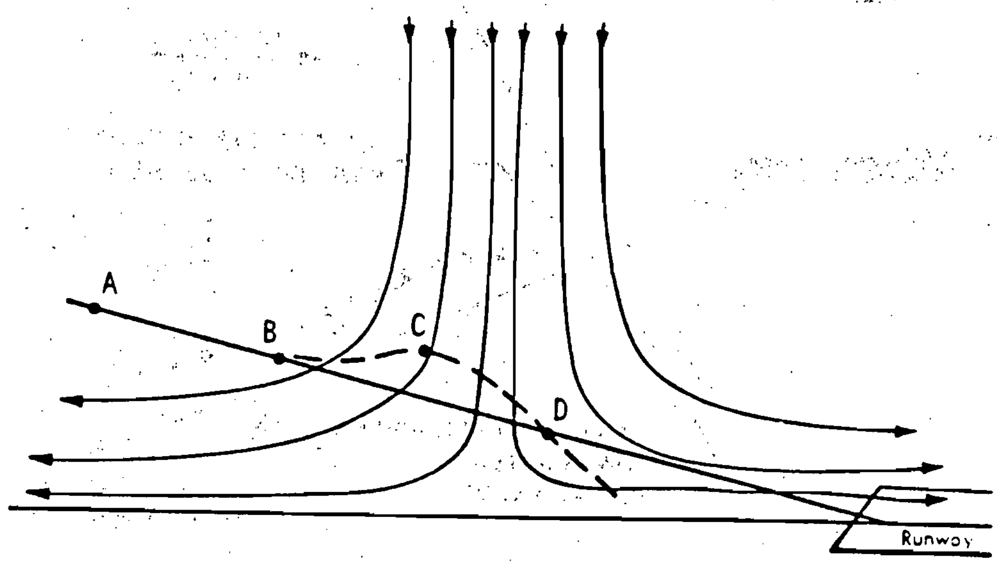


FIGURE 4. DOWNDRAFT SHEAR

b. Angle of Attack in a Downdraft. Downdrafts of falling air in a thunderstorm (sometimes called a "downburst") have gained attention in the last few years due to their role in wind shear accidents. When an airplane flies into a downdraft, the relative wind shifts so as to come down from above the horizon. This decreases angle of attack, which in turn decreases lift, and the airplane starts to sink rapidly. In order to regain the angle of attack necessary to support the weight of the airplane, the pitch attitude must be significantly increased. Such a pitch attitude may seem uncomfortably high to a pilot. However, a normal pitch attitude will result in a continued sink rate. The wing produces lift based on angle of attack - not pitch attitude. Caution should be observed when a pilot has traversed a downdraft and has pitched up sufficiently to stop the sink rate. If that pilot does not lower the nose of the airplane quickly when it exits the downdraft, the angle of attack will become too large and may approach the stall angle of attack. For these reasons, a flight director which senses angle of attack will be preferable to a flight director which calls for a fixed pitch attitude in a downdraft. However, even an angle of attack based flight director may become ineffective if it has an arbitrary pitch up command limit which is set too low (with respect to the downdraft).

c. Climb Performance. In the takeoff and landing configurations, jet transports climb best at speeds near V_2 and V_{ref} (reference speed with landing flaps), respectively. Retracting gear and flaps will even further improve climb performance. However, jet transport airplane manufacturers have pointed out that their airplanes still have substantial climb performance (generally in excess of 1000 fpm) at speeds down to stall warning or stickshaker speed, V_{ss}.

d. Energy Trade. There are only two ways an aircraft can correct for a wind shear. There can be an energy trade or a thrust change. Historically, most pilots have opted for a thrust change since they had no idea how much an energy trade would benefit them. Further information on the energy of flight, therefore, is warranted.

(1) The energy of motion (kinetic energy) is equal to $1/2\ MV^2$ where M is the mass of the airplane and V is the velocity. Kinetic energy is directly convertible to energy of vertical displacement (potential energy). More simply put, airspeed can be traded for altitude or vice versa. It is important to note that adding 10 percent to the speed of the airplane results in a 21 percent increase in kinetic energy because of the velocity being squared. This, of course, explains the concern over stopping an aircraft on the available runway when additional speed is added.

(2) The following table shows the altitude conversion capability of trading 10 or 20 knots of speed for altitude at various initial speeds. Independent of its mass, the capability of the aircraft to trade airspeed for altitude increases as its initial speed increases.

10 Knot Change From - To	Equivalent Altitude, Ft.	20 Knot Change From - To	Equivalent Altitude, Ft.
150-140	128	150-130	247
140-130	119	140-120	230
130-120	111	130-110	212
120-110	102	120-100	195
110-100	93	110-90	177

e. Trading Altitude for Speed. A pilot caught in low level wind shear who finds he is slower than the normal airspeed (even though he has gone to max power) could lower the nose and regain speed by trading away altitude. (This is trading potential energy for kinetic energy.) However, data shows that the penalty for doing this is severe; i.e., a large sink rate is built up and a great deal of altitude is lost for a relatively small increase in airspeed. Therefore, at low altitudes this alternative becomes undesirable. It is preferable to maintain the lower airspeed and rely on the airplane's climb performance at these lower speeds than to push the nose over and risk ground contact. Flight directors which attempt to maintain a given speed (such as V_2 + 10, etc.) will automatically call for trading altitude for airspeed if the airplane is below the proper airspeed. Cases have been observed in simulators where following such a flight director will result in the pilot flying the airplane into the ground. It is the pilot - not the flight director - who should decide if trading altitude for speed is desirable.

f. Trading Speed for Altitude. Conversely, a pilot caught in low level wind shear may pull the nose up and trade speed for altitude; i.e., trade kinetic energy for potential energy. If the speed is above V_2 or V_{ref} (as applicable), then this trade may well be desirable. If at or below V_2 or V_{ref}, such a trade should be attempted only in extreme circumstances. In doing so, the pilot is achieving a temporary increase in climb performance. After he has traded away all the airspeed he desires to trade, he will then be left with a permanent decrease in climb performance. In addition, if ground contact is still inevitable after the trade, there may be no airspeed margin left with which to flare in order to soften the impact. Wind shear simulations have shown, however, that in many cases trading airspeed for altitude (down to V_{ss}) prevented an accident, whereas maintaining V_{ref} resulted in ground impact.

g. Adding Speed for Wind Shear. The possibility of having to trade speed for altitude in wind shear makes it attractive to carry a great deal of extra speed. However, on landing, if the airspeed margin is not used up in the shear and the airplane touches down at an excessive speed, the airplane may not be able to stop on the available runway. It is generally agreed that if a speed margin in excess of 20 knots above V_{ref} appears to be required, the approach should not be attempted or continued.

h. Difficulties of Flying Near V_{SS}. Paragraph f stated that in simulations, wind shear "accidents" had been prevented by trading speed for altitude all the way down to V_{SS}. There are difficulties associated with flying at or near V_{SS} which should be recognized. These include:

(1) The pilot often does not know V_{SS}.

(2) The stickshaker mechanism may be miscalibrated (especially on older aircraft).

(3) The downdraft velocity may vary, which requires a change in pitch attitude to hold speed.

(4) It is hard to fly a precise airspeed in turbulence, which is often associated with wind shear.

(5) Turbulence might abruptly decrease the airspeed from V_{SS} to V_S.

(6) Pilots have historically had little training in maintaining flight at or near V_{SS}.

7. PROCEDURES FOR COPING WITH WIND SHEAR. The most important elements for the flightcrew in coping with a wind shear environment are the crew's awareness of an impending wind shear encounter and the crew's decision to avoid an encounter or to immediately respond if an encounter occurs.

a. Takeoff. If wind shear is expected on takeoff, the PIREPS and weather should be evaluated to determine if the phenomena can be safely traversed within the capability of the airplane. This is a judgment on the part of the pilot based on many factors. Wind shear is not something to be avoided at all costs, but rather to be assessed and avoided if severe. Some rules of thumb for coping with wind shear on takeoff follow:

(1) An increasing headwind or decreasing tailwind will cause an increase in indicated airspeed. If the wind shear is great enough, the aircraft will initially pitch up due to the increase in lift. The pilot should not trim the airplane at the initial high pitch attitude. After encountering the shear, if the wind remains constant, aircraft groundspeed will gradually decrease and indicated airspeed will return to its original value. This situation would normally lead to increased aircraft performance so it should not cause a problem if the pilot is aware of how this shear affects the aircraft.

(2) The worst situation on departure occurs when the aircraft encounters a rapidly increasing tailwind, decreasing headwind, and/or downdraft. Taking off under these circumstances would lead to a decreased performance condition. An increasing tailwind or decreasing headwind, when encountered, will cause a decrease in indicated airspeed. The aircraft will initially pitch down due to the decreased lift in proportion to the airspeed loss. After encountering the shear, if the wind remains constant, aircraft groundspeed will gradually increase and indicated airspeed will return to its original value.

(3) When the presence of severe wind shear is suspected for departure, the pilot should delay takeoff until conditions are more favorable.

(4) If the pilot judges the takeoff wind shear condition to be safe for departure, he should select the safest runway available considering runway length, wind directions, speed, and location of storm areas or frontal areas. He should execute a maximum power takeoff using the minimum acceptable flap position. After rotation, the pilot should maintain an airplane body angle which will result in an acceleration to V_2+25. This speed and takeoff flaps should be held through 1,000 feet AGL. Above 1,000 feet the normal noise abatement profile should be flown. If preflight planning shows that the airplane is runway length limited, or obstruction clearance is a problem, taking off into even a light shear using the V_2+25 procedure should not be attempted. This is because too much of the thrust available for climb is used for acceleration, resulting in the V_2+25 flight path falling below the engine-out flight path at V_2. This would give insufficient clearance for an obstacle in close proximity to the departure end of the runway.

(5) If severe wind shear is encountered on takeoff, the pilot should immediately confirm that maximum rated thrust is applied and trade the airspeed above V_2 (if any) for an increased rate of climb. Depending on the airplane's gross weight, pitch attitudes of 15 to 22 degrees are to be expected during this energy trade, especially if a downdraft is present. A sudden decrease in headwind will cause a loss in airspeed equal to the amount of wind shear. At this point, the pilot should quickly evaluate his airplane's performance in the shear. He/she should monitor airspeed and vertical velocity to ensure that an excessive rate of descent does not develop. If it becomes apparent that an unacceptable rate of descent cannot be prevented at V_2 speed or ground contact appears to be certain at the current descent rate, the pilot should gradually increase the airplane's pitch attitude to temporarily trade airspeed for climb capability to prevent further altitude loss. The trade should be terminated when stickshaker is encountered. The airplane should be held in an attitude that will maintain an airspeed just above the airspeed where the stickshaker was initially encountered. A general rule is to reduce pitch attitude very slightly when stickshaker is encountered. Further pitch reductions in the shear could result in a large descent rate. As the airplane departs the shear, the pilot should reduce the pitch attitude and establish a normal climb. In several recent wind shear accidents, the National Transportation Safety Board (NTSB) has found that the full performance capability of the airplane was not used following a severe wind shear encounter. Post accident studies have shown that, under similar circumstances, had flight techniques of an emergency nature (such as those outlined above) been used immediately, the airplane could have remained airborne and the accident averted.

b. Approach to Landing. Considerations involved in flying an approach and landing or go-around at an airport where wind shear is a factor are similar to those discussed for takeoff.

(1) When wind shear weather analysis, PIREPS, or an analysis of airplane performance indicates that a loss of airspeed will be experienced on an approach, the pilot should add to the V_{ref} speed as much airspeed as he expects to lose up to a maximum of $V_{ref}+20$. If the expected loss of airspeed exceeds 20 knots the approach should not be attempted unless the airplane is specially instrumented and the pilots are specially trained. The pilot should fly a stablized approach on a normal glidepath (using an electronic glidepath and the autopilot when available). In the shear when airspeed loss is encountered, a prompt and vigorous application of thrust is essential, keeping in mind that if airspeed has been previously added for the approach, the thrust application should be aimed at preventing airspeed loss below V_{ref}. An equally prompt and vigorous

reduction in thrust is necessary once the shear has been traversed and normal target speed and glidepath are reestablished to prevent exceeding desired values. Early recognition of the need for thrust is essential. Along with the thrust addition is a need for a noseup rotation to minimize departure below the glidepath. If the airplane is below 500 feet AGL and the approach becomes unstable, a go-around should be initiated immediately. Airspeed fluctations, sink rate, and glide slope deviation should be assessed as part of this decision.

(2) A pilot's chances of safely negotiating wind shear are better if he/she remains on instruments. Visual references through a rain-splattered windshield and reduced visibility may be inadequate to provide him/her with cues that would indicate deviation from the desired flightpath. At least one pilot should, therefore, maintain a continuous instrument scan until a safe landing is assured.

(3) Some autothrottle systems may not effectively respond to airspeed changes in a shear. Accordingly, the thrust should be monitored closely if autothrottles are used. Pilots should be alert to override the autothrottles if the response to increased thrust commands is too slow. Conversely, thrust levels should not be allowed to get too low during the late stages of an approach as this will increase the time needed to accelerate the engines.

(4) Should a go-around be required the pilot should initiate a normal go-around procedure, evaluate the performance of his airplane in the shear, and follow the procedures outlined in the takeoff section of this circular as applicable.

8. SUMMARY. The following summarizes the critical steps in coping with low level wind shear.

a. Be Prepared. Use all available forecasts and current weather information to anticipate wind shear. Also, make your own observations of thunderstorms, gust fronts and telltale indicators of wind direction and velocity available to pilots.

b. Giving and Requesting PIREPS on wind shear are essential. Request them and report anything you encounter. PIREPS should include:

(1) Location of shear encounter.

(2) Altitude of shear encounter.

(3) Airspeed changes experienced, with a clear statement of:

(i) the number of knots involved;

(ii) whether it was a gain or a loss of airspeed.

(4) Type of aircraft encountering the shear.

c. Avoid Known Areas of Severe Shear. When the weather and pilot reports indicate that severe wind shear is likely, delay your takeoff or approach.

d. Know Your Aircraft. Monitor the aircraft's power and flight parameters to detect the onset of a shear encounter. Know the performance limits of your particular aircraft so that they can be called upon in such an emergency situation.

e. Act Promptly. Do not allow a high sink rate to develop when attempting to recapture a glide slope or to maintain a given airspeed. When it appears that a shear encounter will result in a substantial rate of descent, promptly apply full power and arrest the descent with a noseup pitch attitude.

J. A. Ferrarese

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Acting Director
Flight Standards Service

APPENDIX 1. WIND SHEAR RELATED REPORTS

The following reports based on studies made of the wind shear problem are available from the National Technical Information Center, 5285 Port Royal Road, Springfield, Virginia 22216:

Report No.	Title	Report Date
FAA-RD-76-114	Wind Shear: A Literature Search, Analysis and Annotated Bibliography	Feb 1977
FAA-ED-15-2A	Engineering & Development Program Plan	Aug 1977
FAA-RD-77-36	Wind Shear Modeling for Aircraft Hazard Definition (Interim Report)	Mar 1977
FAA-RD-78-3	Wind Shear Modeling for Aircraft Hazard Definition (Final Report)	Mar 1978
FAA-RD-77-33	Wind Shear Characterization	Feb 1977
FAA-RD-77-166	Piloted Flight Simulation Study of Low-Level Wind Shear Phase I	May 1977
	" Phase II	June 1977
	" Phase III	April 1978
NASA-CR-3002	Turbulent Transport Model of Wind Shear in Thunderstorm Gust Fronts	May 1978
FAA-RD-77-184	Low-Level Frontal Wind Shear Forecasts Test Report	May 1978
FAA-RD-78	Gust Front Model Verification Study	Sep 1978
FAA-RD-77-135	Derivation of Groundspeed Information from Airborne DME Interrogators	Nov 1977

Report No.	Title	Report Date
FAA-RD-77-169	Large Aircraft Accident Analysis	December 1977
FAA-RD-77-119	Gust Front Analytical Study	December 1977
FAA-RD-78-7	Simulation and Analysis of the Wind Shear Hazard	December 1977
FAA-RD-77-120	Wind Shear Requirements and Their Application to Laser Systems	February 1978

APPENDIX H

PREVIOUS SAFETY RECOMMENDATIONS ON WIND SHEAR AND DETECTION OF SEVERE WEATHER

As a result of its investigation of the accident at Boston Logan International Airport, Boston, Massachusetts, on December 17, 1973, the Safety Board issued the following 4 safety recommendations to the FAA on October 3, 1974:

> Issue an advisory circular which describes the wind shear phenomenon, highlights the necessity for prompt pilot recognition and proper piloting techniques to prevent short or long landings, and emphasizes the need to be constantly aware of the aircraft's rate of descent, attitude and thrust during approaches using autopilot/autothrottle systems. (A-74-80)
>
> Modify initial and recurrent pilot training programs and tests to include a demonstration of the applicant's knowledge of wind shear and its effect on an aircraft's flight profile, and of proper piloting techniques necessary to counter such effects. (A-74-81)
>
> Expedite the development, testing and operational use of the acoustic doppler wind measuring systems. (A-74-82)
>
> Develop an interim system whereby wind shear information developed from meteorological measurements or pilot reports will be provided to the pilots of arriving and departing aircraft. (A-74-83)

In its response of November 11, 1974, the FAA informed the Safety Board that it concurred with these recommendations, and that appropriate actions were being taken to emphasize wind shear awareness, to expedite the development of doppler radar, and to improve weather reporting. Based upon the actions taken, Safety Recommendations A-74-80 through -83 were classified as "Closed--Acceptable Action."

As a result of its investigation of the accident at John F. Kennedy International Airport, Jamaica, New York, on June 24, 1975, the Safety Board issued the following 14 safety recommendations to the FAA on April 1, 1976:

> Conduct a research program to define and classify the level of flight hazard of thunderstorms using specific criteria for the severity of a thunderstorm and the magnitude of change of the wind speed components measured as a function of distance along an airplane's departure or approach flight track and establish operational limitations based upon these criteria. (A-76-31)
>
> Expedite the program to develop and install equipment which would facilitate the detection and classification, by severity, of thunderstorms within 5 nmi of the departure or threshold ends of active runways at airports having precision instrument approach. (A-76-32)
>
> Install equipment capable of detecting variations in the speed of the longitudinal, lateral, and vertical components of the winds as they exist along the projected takeoff and approach flightpaths within 1 nmi of the ends of active runways which serve air carrier aircraft. (A-76-33)

Require inclusion of the wind shear penetration capability of an airplane as an operational limitation in the airplane's operations manual, and require that pilots apply this limitation as a criterion for the initiation of a takeoff from, or an approach to, an airport where equipment is available to measure the severity of a thunderstorm or the magnitude of change in wind velocity. (A-76-34)

As an interim action, install equipment capable of measuring and transmitting to tower operators the speed and direction of the surface wind in the immediate vicinity of all runway ends and install lighted windsocks near to the side of the runway, approximately 1,000 feet from the ends, at airports serving air carrier operations. (A-76-35)

Develop and institute procedures whereby approach controllers, tower controllers, and pilots are provided timely information regarding the existence of thunderstorm activity near to departure or approach flight paths. (A-76-36)

Revise appropriate air traffic control procedures to specify that the location and severity of thunderstorms be considered in the criteria for selecting active runways. (A-76-37)

Modify or expand air traffic controller training programs to include information concerning the effect that winds produced by thunderstorms can have on an airplane's flightpath control. (A-76-38)

Modify initial and recurrent pilot training programs and tests to require that pilots demonstrate their knowledge of the low-level wind conditions associated with mature thunderstorms and of the potential effects these winds might have on an airplane's performance. (A-76-39)

Expedite the program to develop, in cooperation with appropriate government agencies and industry, typical models of environmental winds associated with mature thunderstorms which can be used for demonstration purposes in pilot training simulators. (A-76-40)

Place greater emphasis on the hazards of low-level flight through thunderstorms and on the effects of wind shear encounter in the accident prevention program for the benefit of general aviation pilots. (A-76-41)

Expedite the research to develop equipment and procedures which would permit a pilot to transition from instrument to visual references without degradation of vertical guidance during the final segment of an instrument approach. (A-76-42)

Expedite the research to develop an airborne detection device which will alert a pilot to the need for rapid corrective measures as an airplane encounters a wind shear condition. (A-76-43)

Expedite the development of a program leading to the production of accurate and timely forecasts of wind shear in the terminal area. (A-76-44)

On May 1, 1981, the FAA informed the Safety Board that it had initiated research programs which, when combined with NEXRAD, would improve the information on wind shear conditions available to pilots. The FAA also informed the Board that it had developed and was in the process of installing a LLWAS which would detect the horizontal wind shear caused by thunderstorm gust fronts and strong cold fronts in the vicinity of an airport. The Safety Board found that the FAA's actions complied with the intent of Safety Recommendations A-76-31, A-76-32, A-76-33, A-76-35, A-76-42, A-76-43, and A-76-44. These recommendations were classified as "Closed—Acceptable Action."

In response to Safety Recommendation A-76-34, the FAA advised the Safety Board on September 24, 1985, that although it is possible to define the wind shear capability of an airplane, too many variables are involved to usefully incorporate this information into an airplane's operation manual. The FAA stated that in response to the intent of this recommendation, the FAA had issued several ACs which significantly increased pilot knowledge of wind shear and increased the possibility of successfully penetrating an inadvertently encountered wind shear. Additionally, the Safety Board notes that since the time this recommendation was made, the FAA and other agencies have initiated several programs both to learn more about the wind shear hazard and to reduce it through identification and avoidance, aircraft instrumentation, and pilot techniques. Based both upon the FAA's response and the Board's knowledge of wind shear programs presently in progress, this recommendation is now classified "Open--Acceptable Action," pending completion of these efforts.

On May 24, 1984, the FAA stated, in response to Safety Recommendation A-76-36, that effective March 15, 1984, the FAA's Air Traffic Control Handbook (7110.65c) included changes that included procedures for the handling of Center Weather Advisories. This action complied with the Board's intent; subsequently, Safety Recommendation A-76-36 was classified as "Closed—Acceptable Action."

In response to Safety Recommendation A-76-37, the FAA informed the Safety Board on June 24, 1980, that the FAA Facility Operation and Administration Handbook (7210.3E) had been revised to specifically assign responsibility for "selecting active runways" and to include "severe weather activity" as one of several factors to be considered on the runway selection process. Safety Recommendation A-76-37 was classified as "Closed--Acceptable Action."

On July 7, 1986, the FAA informed the Safety Board that lessons on turbulence and jetstreams had been included in the air traffic controller training program. In the same response, the FAA stated that Air Carrier Operations Bulletin No. 75-8, Low Level Wind Shear, was issued on December 30, 1975, which required the FAA's principal operations inspectors to ensure that initial and recurrent pilot training programs and tests require pilots to demonstrate their knowledge of low-level wind shear on aircraft performance. Additionally, the FAA informed the Board that Operations Bulletin No. 75-4 had been issued in April 1976, which required accident prevention specialists to emphasize the effects of wind shear. Based upon this response, Safety Recommendations A-76-38, A-76-39, and A-76-41 were classified as "Closed—Acceptable Action."

On April 18, 1980, the FAA informed the Safety Board that extensive investigation and testing had resulted in the development and selection of 10 models of classic wind shear associated with thunderstorms and other wind shear-producing phenomena. These models led to the development of specific pilot operational procedures to avoid or cope with known wind shear conditions. Based upon this action, Safety Recommendation A-76-40 was classified as "Closed—Acceptable Action."

As a result of its investigation of the accident at Denver Stapleton International Airport, Denver, Colorado, on August 7, 1975, the Safety Board issued the following recommendation to the FAA on June 9, 1976:

> Evaluate all air carrier takeoff and climb procedures to determine whether different procedures can be developed and used that will better enable flightcrews to cope with known or suspected low-altitude wind shears. If different procedures are developed, they should be incorporated into the air carriers' flight manuals. (A-76-76)

On August 17, 1976, the FAA stated that, although it did not have airborne techniques or procedures to accommodate a large wind shear like that encountered by the pilots in the Denver accident, the FAA was installing sensors at several airports which were capable of detecting wind patterns and the passage of thunderstorms and gust fronts. With the installation of these sensors, the FAA believed that pilots could avoid or delay takeoffs under conditions of high wind shear. Safety Recommendation A-76-76 was classified as "Closed--Acceptable Alternate Action."

As a result of its investigation of the accident at Philadelphia International Airport, Philadelphia, Pennsylvania, on June 23, 1976, the Safety Board issued the following recommendation to the FAA on February 16, 1978:

> Establish a joint government-industry committee to develop flight techniques for coping with inadvertent encounters with severe wind shears at low altitude. (A-78-3)

Based upon the FAA's research and information on low-level wind shear, the FAA published information concerning techniques for detecting and coping with low-level wind shear in a revision to AC 00-50A, issued January 23, 1979. This circular, developed to provide guidance for recognizing low-level wind shear, describes preflight and in-flight procedures for detecting and predicting wind shear and provides pilot techniques to minimize the effects of wind shear when inadvertently encountered during takeoff or landing. Additionally, Air Carrier Operations Bulletin No. 7-79-1, Low Level Wind Shear, is included in Change 9, Order 8430.17, issued January 10, 1979. This bulletin requests principal operations inspectors to ensure that the information contained in AC 00-50A is reflected in the air carrier's operations procedures and training programs. Safety Recommendation A-78-3 was classified "Closed—Acceptable Action," based upon these actions.

As a result of its investigation of the accident at New Orleans International Airport, Kenner, Louisiana, on July 9, 1982, the Safety Board issued the following 14 recommendations to the FAA on March 25, 1983:

> Review all low level wind shear alert system installations to identify possible deficiencies in coverage similar to the one resulting from the inoperable west sensor at New Orleans International Airport and correct such deficiencies without delay. (A-83-13)

> Make appropriate distribution to the aviation community of information regarding (1) the location and designation of remote sensors of the low level wind shear alert system (LLWSAS) at equipped airports, (2) the capabilities and limitations of the LLWSAS, and (3) the availability of current LLWSAS remote sensor information if requested from tower controllers. (A-83-14)

Record output data from all installed low level wind shear alert system sensors and retain such data for an appropriate period for use in reconstructing pertinent wind shear events and as a basis for studies to effect system improvements. (A-83-15)

Emphasize to pilots on a continuing basis the importance of making prompt reports of wind shear in accordance with prescribed reporting guidelines, and assure that air traffic control personnel transmit such reports to pilots promptly. (A-83-16)

Require that automatic terminal information services advisories be amended promptly to provide current wind shear information and other information pertinent to hazardous meteorological conditions in the terminal area as provided by center weather service unit meteorologists, and that all aircraft operating in the terminal area be advised by blind broadcast when a new automatic terminal information service advisory has been issued. (A-83-17)

Evaluate methods and procedures for the use of current weather information from sources such as radar, low level wind shear alert systems, and pilot reports as criteria for delaying approach and departure operations which would expose the flight to low altitude penetration of severe convective weather. (A-83-18)

Study the feasibility of establishing aircraft operational limitations based on the data available from the low level wind shear alert system. (A-83-19)

Make the necessary changes to display low level wind shear alert system wind output data as longitudinal and lateral components to the runway centerline. (A-83-20)

Use the data obtained from the joint airport weather studies (JAWS) project and other relevant data as a basis to (1) quantify the low level wind shear hazard in terms of effect on airplane performance, (2) evaluate the effectiveness of the low level wind shear alert system and improvements which are needed to enhance performance as a wind shear detection and warning system, and (3) evaluate the aerodynamic penalties of precipitation on airplane performance. (A-83-21)

As the data obtained from the joint airport weather studies (JAWS) project become available (1) develop training aids for pilots and controllers to emphasize the hazards to flight from convective weather activity, (2) develop realistic microburst wind models for incorporation into pilot flight simulator training programs, and (3) promote the development of airborne wind shear detection devices. (A-83-22)

Expedite the development, testing, and installation of advanced doppler weather radar to detect hazardous wind shears in airport terminal areas and expedite the installation of more immediately available equipment such as add-on doppler to provide for detection and quantification of wind shear in high risk airport terminal areas. (A-83-23)

Encourage industry to expedite the development of flight director systems such as MFD-Delta-A and head-up type displays which provide enhanced pitch guidance logic which responds to inertial speed/airspeed changes and ground proximity and encourage operators to install these systems. (A-83-24)

Recommend to air carriers that they modify pilot training on simulators capable of reproducing wind shear models so as to include microburst penetration demonstrations during takeoff, approach, and other critical phases of flight. (A-83-25)

Advise air carriers to increase the emphasis in their training programs on the effective use of all available sources of weather information, such as preflight meteorological briefings, ATIS broadcasts, controller-provided information, PIREPS, airborne weather radar, and visual observations, and provide added guidance to pilots regarding operational (i.e., 'GO/NO GO') decisions involving takeoff and landing operations which could expose a flight to weather conditions which could be hazardous. (A-83-26)

In its response of July 21, 1983, the FAA informed the Safety Board that the LLWSAS had been placed on the National Airspace Performance Reporting System List, which requires that all deficiencies must be reported and repairs accomplished on a priority basis. This action complied with the intent of Safety Recommendation A-83-13, which was subsequently classified as "Closed—Acceptable Action." The FAA also reported that a number of actions were in progress which addressed the following areas:

- Development of a plan for the installation of data recorders on LLWSAS
- The effect of wind shear on aircraft performance and the effectiveness of wind shear detection and reporting
- Development of improved wind shear models and training aids for pilots
- Improved dissemination of LLSWAS information
- Development of updated realistic microburst/downburst models for simulator training
- Development of airborne wind shear detection systems
- Development and installation of airport terminal doppler weather radar.

Pending the FAA's completion of these actions, Safety Recommendations A-83-15, A-83-21, A-83-22, and A-83-23 were classified as "Open—Acceptable Action."

On April 2, 1985, the FAA reported that it had completed its planned actions with regard to dissemination of information regarding LLWSAS installations and capabilities, pilot reporting of wind shear encounters, updating of the automatic terminal information service advisory, and efforts to educate and inform pilots on the need to review all pertinent weather information. Based upon the actions taken, Safety Recommendations A-83-14, A-83-16, A-83-17, and A-83-26 were classified as "Closed--Acceptable Action."

Also in the letter of April 2, 1985, the FAA informed the Safety Board that it was continuing its efforts in the following areas:

- o Developing improved wind shear detection, classification, and reporting systems, so as to develop criteria for delaying approach and departure operations
- o Improving the capability of LLWSAS to detect near terminal wind shears
- o Development of improved wind shear simulator training models.

Pending the FAA's completion of these efforts, Safety Recommendations A-83-18, A-83-19, A-83-20, and A-83-25 were classified as "Open—Acceptable Action."

With regard to Safety Recommendation A-83-24, the FAA informed the Safety Board that it had published AC No. 120-41, "Criteria for Operational Approval for Airborne Wind Shear Alerting and Guidance Systems." The Board found the AC to be an excellent guide for the development of an airborne wind shear alert and flight guidance system. Additionally, the Board believes that the FAA has encouraged industry to expedite the development of improved flight director systems. Pending completion of the FAA's efforts in this area, Safety Recommendation A-83-24 was classified "Open--Acceptable Action."

On April 18, 1986, the FAA provided the Safety Board with a draft copy of the Integrated Wind Shear Program Plan for comment. This plan addressed several recommendations issued by the Safety Board to the FAA. The plan describes the wind shear research and development activities currently being pursued by the FAA in its efforts to provide information to flightcrews so that they can avoid hazardous wind shear. Safety Recommendations mentioned in the FAA's program plan are A-83-14 through -17 and A-83-20 through -26. All of these recommendations resulted from the Safety Board's investigation of the Kenner accident. The FAA's program plan provides greater detail to the efforts mentioned in the FAA's letters of July 21, 1983, and April 2, 1985.

Safety Recommendations A-83-14, -15, and -20

The FAA's plan includes the continued development of improvements in the LLWAS system and in the ability to record data from all LLWAS systems. Improvements in LLWAS include development, implementation, and operational testing of improved algorithms to enhance the current six-station system ability to detect microbursts better; further examination of LLWAS sensor network geometries to establish the optimal layout of low-altitude wind shear detection; significant improvement of the detection algorithms as enhanced by increasing the total number of sensors; development of improved display systems for ATC tower; and integration of the LLWAS data into the terminal Doppler weather radar system for those airports where it seems appropriate to have both systems.

The FAA's plans concerning LLWAS will comply with the Safety Board's intent in issuing the subject recommendations if the FAA's plans are implemented as presented and on schedule. The Safety Board believes that the currently installed LLWAS systems provide one of the best near-term data collection devices to help prevent additional aircraft encounters with wind shear. Therefore, every effort should be made to ensure that these systems provide the best possible data until such time as Doppler radar or other systems are available. Safety Recommendations A-83-15 and -20 will remain classified as "Open--Acceptable Action" pending completion of the FAA's planned efforts. The action taken by the FAA to place LLWAS systems on the National Airspace Performance Reporting satisfies the intent of Safety Recommendation A-83-14, which has been classified as "Closed--Acceptable Action."

Safety Recommendation A-83-16

In its letter of April 2, 1985 the FAA informed the Safety Board that it had prepared a film on the importance of pilots reporting wind shear, issued an advisory circular concerning low-level wind shear, and modified the AIM to stress the need for pilots to report any wind shear encounter. Additionally, the FAA stated its commitment to continue to emphasize this issue in the airmen's education program. The Safety Board found this action to be satisfactory and subsequently classified Safety Recommendation A-83-16 as "Closed—Acceptable Action." The FAA's wind shear program plan continues to stress this subject by making ATC personnel more aware of the importance of obtaining detailed wind shear reports from pilots, keeping this information current, and relaying wind shear reports in a timely manner.

Safety Recommendation A-83-17

In its program plan, the FAA recognizes that weather information is generally not transmitted quickly enough to aid controllers and pilots in the determination of possible wind shear. The FAA plans to explore how to implement weather hazard displays that link the current NWS network and the ATC tower. In addition, limited artificial intelligence concepts may be developed to provide controllers with some minor degree of improved information prior to the implementation of Doppler radar. The Safety Board agrees with the FAA's assessment that, until the full implementation of TDWR systems, improved communication of weather data is required to ensure that tower personnel can provide timely warnings of potential wind shear conditions. The Safety Board found that the FAA had appropriately addressed this subject in its letter of April 2, 1985, which stated that FAA Handbook 7210.3G had been changed to require that all weather data pertinent to operations within the terminal area be part of the ATIS broadcast. While Safety Recommendation A-83-17 has been classified as "Closed--Acceptable Action," the Safety Board is pleased that the FAA plans to continue to emphasize this subject to both airmen and controllers.

Safety Recommendation A-83-21

The FAA's support of research work at NASA which, in part, addresses the effects of heavy rain on aircraft performance, has the potential for complying with the intent of this recommendation. Additionally, the FAA states in its program plan that it will continue to support work being done in this area by the academic sector and several other agencies of government. The Safety Board believes that the FAA is taking reasonable actions to comply with this recommendation. This recommendation will remain open until the FAA reports its conclusions about the effects of precipitation on aircraft performance.

Safety Recommendations A-83-22, -25, and -26

The FAA recognizes in its program plan that one of the keys to preventing wind shear accidents is to transfer, through urgent information and education campaigns, the best and most useful of wind shear research results to pilots, air traffic controllers, meteorologists, and all participants in the airline operations and training departments.

The FAA has contracted the Boeing Company to produce a wind shear education and training program by December 1986. The program is expected to contain background resource material explaining the wind shear weather phenomena, a definition of precautionary procedures to use in case of suspected wind shear, a definition of airplane response and pilot response under these circumstances, as well as a description of effective "hands-on" simulator training to reinforce the classroom resource material. Based upon work already accomplished, a set of standardized wind shear models that can be used in simulators to teach effective wind shear recovery has been developed and provided to industry. The FAA plans to expand its activities to develop a simulator training program stressing the unique characteristics of general aviation aircraft and helicopters. The Safety Board believes that the FAA is taking appropriate actions with regard to these recommendations and will maintain these recommendations in an "Open--Acceptable Action" status, pending completion of the FAA efforts.

Safety Recommendation A-83-23

The FAA is currently committed to developing and implementing the NEXRAD system with initial installations scheduled for 1987. To have this valuable wind shear detection system more quickly available at airports with higher potentials for wind shear, the FAA is planning a near term effort to reconfigure some of the NEXRAD systems for use as TDWR systems. The FAA is continuing to support the development of NEXRAD algorithm technique development that will further aviation hazard detection, and the transfer of NEXRAD data to the appropriate FAA operational user. In addition, because the FAA recognizes that Doppler radar will continue to evolve, it will therefore have to monitor improvements as they are developed by industry and other agencies. The FAA plans to work with the other NEXRAD agencies, the NWS, and the Department of Defense to stay current with improvements in NEXRAD technology. Pending the installation of the NEXRAD and TDWR systems, Safety Recommendation A-83-23 has been classified as "Open--Acceptable Action."

Safety Recommendation A-83-24

The FAA has developed an AC that defines the criteria for approving the development and installation of airborne wind shear and flight guidance systems. The FAA is currently involved with NASA, the National Center for Atmospheric Research, and industry to develop a program plan to implement an airborne wind shear detection and avoidance system. This program centers on developing an airborne Doppler weather radar with the additional aim of developing the system requirements for an operational detection and avoidance system. The Safety Board notes that the FAA has encouraged the development and installation of these devices, and therefore, this recommendation has been classified as "Open--Acceptable Action," pending the completion of the FAA's efforts in this area.

As a result of its investigation of the accident at Denver Stapleton International Airport, Denver, Colorado, on May 31, 1984, the Safety Board issued the following recommendations to the FAA on April 15, 1985:

> In cooperation with air carriers and manufacturers develop a common wind shear training program, and require air carriers to modify airline training syllabi to effect such training. (A-85-26)
>
> Conduct research to determine the most effective means to train all flightcrew members in cockpit resource management, and require air carriers to apply the findings of research to pilot training programs. (A-85-27)

On July 22, 1985, the FAA informed the Safety Board about the FAA's latest plans and progress towards the development of an air carrier wind shear training document and on the FAA's Aviation Behavioral Technology Program with regard to cockpit resource management. The Safety Board found that the plans described by the FAA would comply with the intent of Safety Recommendations A-85-26 and A-85-27 when implemented. Accordingly, both recommendations were classified "Open--Acceptable Action," pending completion of the FAA's efforts.

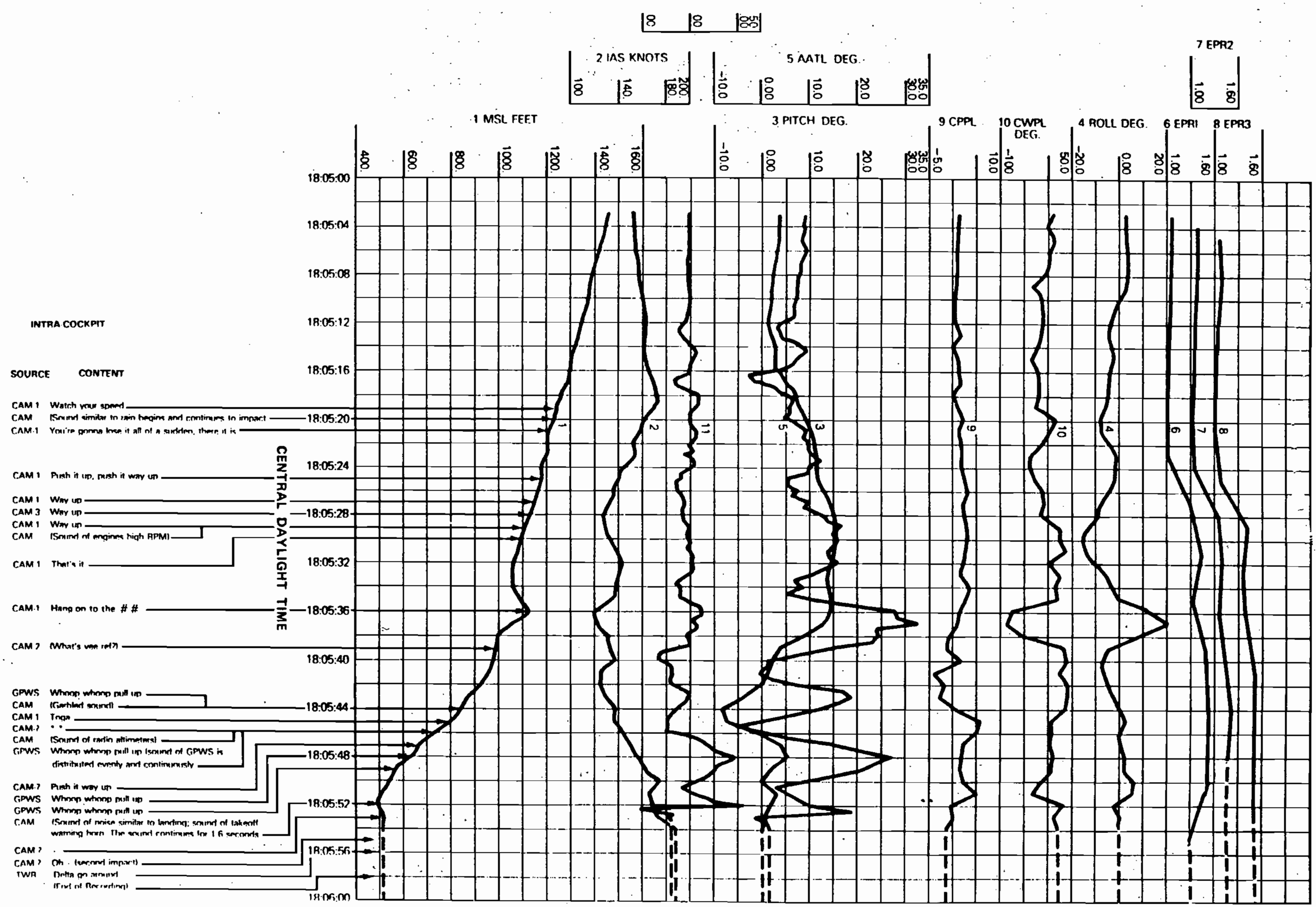
In addition, the Safety Board has investigated three accidents which, while not involving low-level wind shear situations, resulted in the issuance of recommendations to the FAA on the subject of the timely detection of severe weather. These accidents were Ozark Airlines at St. Louis, Missouri, on July 23, 1973; Southern Airways, Inc., at New Hope, Georgia, on April 4, 1977, and Air Wisconsin at Valley, Nebraska, on June 12, 1980. These accidents resulted in Safety Recommendations A-74-13, A-77-63, and A-80-118, respectively, which follow:

> Develop and install terminal air traffic control radar capable of locating severe weather and displaying convective turbulence. This radar should be used to vector aircraft around severe weather. (A-74-13) (issued April 18, 1974)
>
> Expedite the development and implementation of an aviation weather subsystem for both en route and terminal area environments, which is capable of providing real-time display of either precipitation or turbulence, or both and which includes a multiple-intensity classification scheme. Transmit this information to pilots either via the controller as a safety advisory or via an electronic data link. (A-77-63) (issued September 27, 1977)
>
> Expedite the development of an integrated weather radar/air traffic control radar single video display system capable of providing multiple weather echo intensity discrimination without derogation of air traffic control radar intelligence. (A-80-118) (issued November 19, 1980)

The FAA provided an additional response to these recommendations on May 5, 1986. In its response, the FAA informed the Safety Board of several ongoing programs that, when completed, would satisfy the intent of these recommendations. The Safety Board requested to be periodically informed of the progress of these programs. Pending completion of the FAA's efforts regarding Safety Recommendations A-74-13, A-77-63, and A-80-118, they are now classified as "Open--Acceptable Action."

APPENDIX I

DFDR/CVR INTEGRATED PLOT



DFDR/CVR CORRELATION