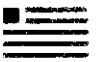

U·S AIRWAYS

PARTY SUBMISSION OF US AIRWAYS, INC.

TO THE

NATIONAL TRANSPORTATION SAFETY BOARD

USAIR FLIGHT 427

SEPTEMBER 8, 1994

ALIQUIPPA, PENNSYLVANIA

DCA–94–MA–076

SUBMITTED SEPTEMBER 30, 1997

2345 Crystal Drive Arlington, VA 22227

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POST-HEARING SUBMISSION OF US AIRWAYS, INC.

USAir Flight 427
Crash Near Aliquippa, Pennsylvania
September 8, 1994

I. INTRODUCTION

The purpose of this submission is to provide the National Transportation Safety Board with US Airways' analysis and conclusions regarding the circumstances and causes of the crash of USAir Flight 427. As the investigation is ongoing, US Airways reserves the right to supplement this submission.

This extensive, three-year investigation has yielded a great deal of information and analysis. The data demonstrates, and all parties seem to agree, that USAir Flight 427's rudder moved to a full-left position shortly after the aircraft encountered wake vortices generated by a preceding aircraft. It is also clear that the wake vortex encounter did not directly cause the accident.

The investigation revealed that the Boeing 737 rudder control system has certain anomalies which may have resulted in a rudder reversal or uncommanded full rudder deflection on the accident aircraft. As a result, the Board has issued recommendations to correct problems that might exist in the Boeing 737 rudder control system. In addition, US Airways has implemented procedures to deal with potential rudder control problems in the unlikely event they should occur.

This submission does not analyze possible accident causes that were investigated and found not to be a factor, for they are quite numerous and undisputed. Similarly, this submission does not analyze the various possible rudder control system failure modes because the

investigation of this issue is ongoing and modifications of that system already recommended by the Safety Board should protect against future accidents. Instead, this submission concentrates on the actions of the flight crew and facts which establish that the flight crew did not cause the full-left rudder deflection, and that they acted properly in responding to this emergency.

II. EXECUTIVE SUMMARY

A. ACCIDENT SUMMARY

On September 8, 1997, USAir Flight 427 was approaching the Pittsburgh International Airport at 6,000 feet and 190 knots when it encountered the wake vortices of a preceding Boeing 727. Approximately three seconds after encountering the wake vortex, the accident aircraft's rudder suddenly moved to a full-left position. The aircraft began to yaw and roll left, and the nose began to drop. As the crew attempted to regain control of the aircraft, the roll and yaw continued, and the nose continued to drop. Approximately 23 seconds after the onset of the full rudder deflection, the aircraft impacted the ground in a nearly vertical attitude, still rolling and yawing.

B. INVESTIGATION AND ANALYSIS

1. FLIGHT CREW QUALIFICATIONS

The flight crew of USAir Flight 427, Captain Peter Germano and First Officer Charles Emmett, were experienced, highly qualified and fully trained pilots. They had a combined total of over 14,000 hours of flight time as USAir pilots, including nearly 8,000 hours in the Boeing 737. Captain Germano had flown with USAir for over 13 years, and First Officer Emmett for seven years. Each had extensive aviation experience prior to their USAir employment. USAir flight training records and interviews with other pilots confirmed that the USAir 427 flight crew

were properly trained, capable, well-respected, and approached their duties with exemplary professionalism.

2. FLIGHT CREW PERFORMANCE

The Aircraft Performance Group and Human Performance Group studied several aspects of aircraft and pilot performance in an attempt to determine whether the flight crew had commanded the full-left rudder deflection that caused the aircraft to begin its yaw and roll upset and, regardless of the cause of the rudder deflection, whether the flight crew acted properly in dealing with the emergency. To make this determination, the Aircraft and Human Performance Groups investigated several possible indicators of crew actions, including wake vortex encounters, disorientation and vestibular effects, speech patterns, rudder pedal damage patterns, B-737 crossover speeds, and unusual attitude training and procedures.

a. Flight Crew Control Inputs

The facts developed in this investigation do not support a conclusion that the flight crew commanded the full-left rudder deflection that caused this accident.

The Aircraft Performance Group conducted flight tests to determine the reaction of a Boeing 737 when flown into the wake vortices of a Boeing 727 under the same conditions that prevailed at the time of the USAir Flight 427 accident. These test encounters resulted in aircraft attitude deviations almost identical to those experienced by Flight 427 during its wake vortex encounter. The pilots who flew the tests reported that the wake vortex encounters were easily recoverable and were not disorienting. They also reported that at no time did they feel they were close to losing control of the Boeing 737. An airline pilot with extensive experience in the Boeing 737 participated in the tests and reported that the test encounters were virtually identical

to those he had experienced while flying the line, and that such encounters are frequent and routine for airline pilots. The flight tests showed it to be extremely unlikely that the highly-experienced USAir Flight 427 flight crew were so startled by a routine wake vortex encounter that they mistakenly applied and held full-left rudder and full-right aileron for 23 seconds as the aircraft spiralled into the ground.

The Human Performance Group examined, with the aid of a NASA expert, the possibility that Captain Germano and First Officer Emmett may have become disoriented during the wake vortex encounter, leading to an incorrect application of flight controls. They found that circumstances conducive to vestibular disorientation -- lack of visual references combined with sudden, violent aircraft motion or subtle, gradual aircraft motion -- were absent during the USAir Flight 427 accident. In addition, the cockpit voice recorder tape revealed the pilots were aware of the aircraft's attitude, but could not control it. Because the circumstances giving rise to disorientation were not present, and the pilots were aware of the aircraft's attitude, there is no reason to suspect that Captain Germano or First Officer Emmett were disoriented during the accident sequence.

The high quality of the Cockpit Voice Recorder tape made it possible to conduct a detailed analysis of the voices of Captain Germano and First Officer Emmett during the accident sequence. The Human Performance Group's analysis, conducted with the assistance of three experts in the field, showed that First Officer Emmett was flying the aircraft. The analysis also showed that Captain Germano was not participating in physical control of the aircraft until immediately prior to impact, if at all. The voice analysis shows that Captain Germano was attempting to analyze the nature of the problem while directing the recovery attempt. There is

no evidence that both pilots attempted to simultaneously apply flight control inputs during the wake vortex encounter or the full rudder deflection that followed.

The cockpit voice recorder also shows that the pilots' voices during the wake vortex encounter were unexcited. Even several seconds after the onset of the full rudder deflection, their voices still did not demonstrate "startle" or panic. The voice analysis studies provide no evidence that the flight crew were so startled by their wake vortex encounter that they unknowingly and incorrectly applied full rudder, full opposite aileron, and held these cross-controlled inputs for 23 seconds as the aircraft spiralled into the ground.

b. Flight Crew Response to Full-Left Rudder Deflection

Analysis and flight tests conducted after the accident revealed that at the time of the wake vortex encounter, USAir Flight 427, although flying at the correct airspeed, was nonetheless flying at an airspeed below which the Boeing 737's lateral controls (ailerons and spoilers) were unable to overcome the roll induced by a fully-deflected rudder. This latter speed is known as the "crossover speed," although the term and the concept had not been made known to USAir or the airline industry prior to this accident. Below the crossover speed, an aircraft that experiences an uncommanded, fully-deflected rudder cannot be recovered unless the crew accelerates the aircraft to a speed above the crossover speed, which requires that the crew immediately descend toward the ground to gain speed as quickly as possible. Such a maneuver under the circumstances would be completely inconsistent with training, pilot instincts and expectations, unless the crew had been aware of the crossover speed concept and the crossover speed for their flight configuration.

III. FACTUAL INFORMATION

A. HISTORY OF USAIR FLIGHT 427

On September 8, 1994 at approximately 1903 Eastern Daylight Time, USAir Flight 427, a regularly scheduled revenue flight from Chicago, Illinois to Pittsburgh, Pennsylvania, crashed while approaching the Greater Pittsburgh International Airport.

The Captain, Peter Germano, and the First Officer, Charles B. Emmett, III, were on the last day of a three-day trip at the time of the accident. The accident flight was their tenth flight together during the trip. Between them, these pilots had over 40 years of aviation experience and over 21,000 flight hours, approximately 7,700 of which were in the Boeing 737.

During the trip, the crew's on-duty time had never exceeded nine hours during any one day, and off-duty time had never been less than 13 hours between duty periods. Human Performance Group Factual Report, Exhibit 14A at 4.

Captain William Jackson, a USAir DC-9 Captain, flew in the cockpit observer seat ("jumpseat") during the flight from Charlotte, North Carolina to Chicago, Illinois, which immediately preceded the accident flight. Testimony of Captain William Jackson, Transcript of Proceedings before the National Transportation Safety Board, January 23, 1995, 41 (hereinafter, "Jackson Tr."). Captain Jackson stated that Captain Germano flew the leg from Charlotte to Chicago. Operations Group Report, Exhibit 2A at 3. He described the crew as "capable and very professional" and reported they used aircraft checklists and made all the standard and required call-outs. Jackson Tr. at 47. Captain Jackson is experienced on the B-737-300, having flown 2,800 hours in that aircraft as both Captain and First Officer. Id. at 49.

He did not observe any aircraft problems and did not see any outstanding Minimum Equipment List notations in the cockpit. Id. at 45-46.

The aircraft, a Boeing 737-300, Registration Number N513AU, was on its seventh flight of the day when the accident occurred. There had been no discrepancies reported on any of the previous flights, and there were no outstanding Minimum Equipment List items. Operations Group Report, Exhibit 2A at 3. The aircraft's inspections were current, including three rudder functional inspections required by Airworthiness Directive AD 94-01-07 during the previous six months. Maintenance Records Group Chairman's Factual Report, October 14, 1994, Exhibit 11A at 4.

The departure from Chicago and flight into the Pittsburgh area were uneventful. Air traffic control tapes and the Cockpit Voice Recorder indicate First Officer Emmett was flying this leg. Operations Group Report at 4. External and intra-cockpit communications were routine, including appropriate reading of checklists. Id. The weather was clear, it was still daylight, and there was a distinct horizon.

At 1902 EDT, Pittsburgh Approach Control directed USAir Flight 427 to turn left to a heading of 100°. As previously directed by Air Traffic Control, USAir Flight 427 was level at 6,000 feet (MSL) and maintaining 190 knots indicated airspeed. The landing gear was up with Flaps 1 selected and the autopilot engaged. The accident aircraft was 4.2 miles behind a Boeing 727 aircraft, Delta Airlines Flight 1083, which was descending to 6,000 feet. The two aircraft were assigned the same heading.

As USAir Flight 427 approached its assigned heading of 100° and had almost rolled out of its slight left bank, the flight data recorder showed small changes in airspeed, attitude, and

vertical acceleration.[1] The autopilot was still engaged. Within a second, the cockpit voice recorder recorded comments by the pilots ("Sheez"; "Zuh") and a thump on the aircraft. Over the next three seconds, the aircraft rolled left to approximately 18° of bank, then rolled slightly back to the right, but never reached a wings level attitude. During this three seconds, the CVR recorded another thump on the aircraft. The Captain commented, "Whoa," and the CVR recorded the sound of the aircraft trim wheel turning at autopilot trim rates. The FDR recorded an increase in the amount of aft control column being commanded as the autopilot maintained level flight.

At 1903:01 EDT, the aircraft's heading slewed suddenly and dramatically to the left. The Captain said, "Hang on," and the CVR recorded the sound of the First Officer grunting.

One second after the onset of the sudden yaw, the Captain said, "Hang on" again as the left yaw continued. The aircraft's roll attitude, which previously had begun to decrease, suddenly began to increase to the left and reached 30°. The aircraft's pitch attitude began to decrease rapidly. At this point, the rate of descent was approximately 2,400 feet per minute ("fpm"). The CVR recorded the sound of the autopilot being disconnected.

One second later, two seconds after the onset of the yaw event, the Captain again said, "Hang on." The left yaw and roll continued, and two seconds later (1903:05), the aircraft passed 55° of left bank, still rolling and yawing. The nose was now 10° below the horizon. The Captain again said, "Hang on." The rate of descent at this point was approximately 3,000 fpm. The control column was moving aft and vertical "G" loading increased.

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[1]All flight parameters noted in this submission are from the Group Chairman's Report of Investigation, Flight Data Recorder Factual Report, November 28, 1994, Exhibit 10A, Attachment IV. Cockpit Voice Recorder data are taken from the Specialist's Factual Report of Investigation, Cockpit Voice Recorder, October 5, 1994, Exhibit 12.

At 1903:07, six seconds after the onset of the yaw, the aircraft's pitch attitude was approaching 20 degrees below the horizon. The left bank had increased to 70°. The descent rate was now approximately 3,600 fpm. At this point, the aircraft stalled. Left roll and yaw continued, and the aircraft rolled through inverted flight as the nose reached 90° down, approximately 3,600 feet above the ground.

The aircraft continued to roll after reaching a vertical dive, but the nose began to rise. Approximately 2,000 feet above the terrain, as the aircraft's attitude passed 40° nose low and 15° of left bank, the left roll hesitated briefly. At this point, approximately five seconds prior to impact, the Captain said, "Pull," but the aircraft immediately resumed its left roll, and the nose again dropped. Five seconds later, the aircraft impacted the ground in nearly 80° of dive, almost 60° of left bank, and at 261 knots indicated airspeed. The 132 passengers and crewmembers aboard the aircraft were killed.

IV. INVESTIGATION AND ANALYSIS

A. FLIGHT CREW QUALIFICATIONS

1. CAPTAIN PETER GERMANO

a. Factual Investigation

At the time of the USAir Flight 427 accident, Captain Germano had accumulated 9,112 hours at USAir. He had accumulated 4,064 hours in the Boeing 737, of which 3,296 were flown as a Captain. Operations Group Factual Report, Exhibit 2A, at 7. Captain Germano's lifetime flight experience in all aircraft was approximately 12,000 hours. Id.

Captain Germano was 45 years old at the time of the accident. Id. at 5. His flying career began at age 20 in 1969, when he received his Private Pilot Certificate from the FAA.

Id. at 5. He completed United States Air Force ("USAF") pilot training in December 1973. Human Performance Group Chairman's Factual Report, Second Addendum, October 5, 1995 at 5. Although USAF flight records from that period are not available, the syllabus for USAF pilot training at the time required that each student receive extensive instruction and demonstrate proficiency in spin recoveries, unusual attitude recoveries, and aerobatic maneuvers. Human Performance Group Chairman's Factual Report, Third Addendum, October 27, 1995 at 2.

Following USAF pilot training, Captain Germano flew the O-2 aircraft, the USAF version of the Cessna 337. Id. The aircraft was used in the Forward Air Controller role, which required abrupt maneuvers and rapid changes in aircraft attitude, often at low altitude. Id. at 2-3. Captain Germano flew the O-2 from February 1974 to March 1979, logging over 500 hours as Pilot in Command. Human Performance Group Factual Report, Second Addendum, Exhibit 14X-A, at 5.

Captain Germano received his Commercial Pilot Certificate in 1974. Operations Group Factual Report at 5. Prior to his employment at USAir, Captain Germano was a flight engineer for Braniff Airlines. Human Performance Group Factual Report, Second Addendum, at 5. Captain Germano was hired by USAir in 1981 as a B-727 Second Officer, then progressed to become a BAC 1-11 First Officer, a B-737 First Officer, and then a B-737 Captain.

The Operations Group gathered evaluator comments on Captain Germano's most recent training and evaluation events, as well as post-accident peer reports. Captain Germano had received five simulator evaluations and training sessions in the 13 months preceding the accident. Operations Group Factual Report, Exhibit 2A, at 6. In each of these training sessions and evaluations, he successfully completed all the required tasks without a discrepancy. There were

no negative comments on Captain Germano's performance from any of the five Check Airmen who administered these evaluations and training sessions. Id. The Check Airman who conducted Captain Germano's requalification simulator in April 1994 reported that the training went well with no problems. Id. Similarly, the Check Airman who flew three requalification flights with Captain Germano in May 1994 reported that Captain Germano was "very meticulous, very professional, paid attention to detail, ran complete checklists, and followed all procedures." Id. Three first officers who had flown with Captain Germano during the 60 days preceding the accident described him as flying "by the book" and as "very proficient," "very thorough," and "not excitable." Two of these first officers stated that Captain Germano's greatest strength was crew coordination. Id.; Human Factors Group Report, Exhibit 14A, at 3. Captain William Jackson flew in the cockpit jumpseat on the Charlotte-to-Chicago leg immediately preceding the accident flight. He reported Captain Germano provided a thorough jump seat briefing and invited input from the First Officer and from Captain Jackson on procedures at Chicago, as Captain Germano had not landed there recently. Human Performance Group Chairman's Factual Report, October 31, 1994, Exhibit 14A, at 5.

Captain Germano upgraded to B-737 Captain in September 1988. He successfully completed each element of the required 12 hours of simulator upgrade training and 21 supervised line check flights. Captain Germano successfully accomplished all other training and evaluations received in the time between his upgrade to Captain and the accident.

b. Analysis

Even as far back as his 1988 captain upgrade training, six years before the accident, Captain Germano's training and evaluation records indicate he was a very capable pilot.[2] Comments by Check Airmen and First Officers who evaluated or flew with Captain Germano near the time of the accident consistently painted a picture of a mature, thorough Captain. Two first officers reported Captain Germano's greatest strength was crew resource management. This comment is borne out by the testimony of Captain Jackson, who witnessed Captain Germano's use of Cockpit Resource Management techniques when he sought the counsel of his fellow pilots before flying into the complex Chicago air traffic environment.

Captain Germano's flight training record and the testimony of his fellow pilots indicate he was a thorough, proficient, and disciplined captain. In addition, Captain Germano's training records do not indicate he ever encountered difficulty with the application of the appropriate rudder at the correct time, even in the numerous engine-out scenarios practiced and evaluated during his Captain upgrade training or proficiency and recurrency training simulators. Nor does the record indicate any difficulty with orientation or controlling aircraft attitude during the numerous steep turns, approaches to stalls, and other advanced maneuvers practiced and evaluated in the simulator. To the contrary, Captain Germano's military training included unusual attitude recoveries, acrobatics, and spin recoveries. Additionally, for five years he flew a military mission requiring frequent abrupt changes in aircraft attitude. To a pilot with such

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[2]The Aviation Investigation Manual recommends the Operations Group initially examine the pilots' training records for the preceding two years. NTSB Aviation Investigation Manual, Vol. II, p. II-F-74. Even though nothing in the pilots' records for the two years preceding the accident would indicate a need to examine older records, US Airways' Submission will discuss these pilots' records as far back as their checkouts in the positions they held at the time of the accident.

experience, the routine wake vortex encounter experienced by USAir Flight 427 would not pose any significant difficulty in recognition or recovery.

The facts brought to light in this investigation show clearly that Captain Germano was fully qualified and properly trained to function as the Captain of USAir Flight 427. His training and experience indicate he possessed the skill and training needed to recognize, analyze, and successfully recover a normally functioning aircraft from the routine wake vortex encounter experienced by USAir Flight 427.

2. FIRST OFFICER CHARLES B. EMMETT

a. Factual Investigation

First Officer Emmett was 38 years old at the time of the accident. Human Performance Group Factual Report, Exhibit 14A, at 3. He started taking flying lessons as a teenager, and began his aviation career as a corporate pilot. Id. He was hired by Piedmont Airlines (later merged with USAir) on February 2, 1987 as a First Officer on the F-28 aircraft. At the time of the USAir Flight 427 accident, First Officer Emmett had accumulated 4,919 hours as a pilot with Piedmont and USAir, all of it as a First Officer. This time included 3,644 hours in the Boeing 737. Operations Group Chairman's Report, Exhibit 2A at 9. In all, he had accumulated over 9,000 hours in his flying career. Id.

First Officer Emmett received three evaluations and training sessions in the seventeen months preceding the USAir Flight 427 crash. He completed each of these evaluations without a discrepancy. Id. The Check Airman who administered First Officer Emmett's last Proficiency

Training session in the simulator on May 12, 1994 recalled that First Officer Emmett was well prepared for the training and that his performance in the flying and oral evaluations was "sharp." Id.

A month before the USAir Flight 427 accident, First Officer Emmett was the "pilot flying" when the B-737 he was flying experienced a hydraulic system failure necessitating a heavyweight precautionary landing. Human Performance Group Chairman's Factual Report, October 31, 1994, Exhibit 14A, at 3. During the incident, First Officer Emmett transferred aircraft control to the captain, then assisted the captain in executing diagnostics and accomplishing the successful heavyweight landing. Id. The captain described First Officer Emmett's performance during the incident as "great," and indicated First Officer Emmett was calm throughout the situation. Id.; Operations Group Chairman's Factual Report, Exhibit 2A at 9. Other Captains who had flown with First Officer Emmett within the 60 days preceding the accident described his piloting skills as "exceptional" and his performance as "outstanding." Operations Group Report, Exhibit 2A, at 9.

First Officer Emmett's transition training into the Boeing 737 began in April 1989. He received four simulator practice sessions, all elements of which he performed without a discrepancy. As part of the transition training, he received 12 Initial Operating Experience evaluation flights in the B-737, all of which he also completed without a discrepancy. On May 1, 1989, First Officer Emmett successfully completed his B-737 Transition Proficiency Check, again without a discrepancy. On May 8, 1989, First Officer Emmett completed four hours of Line Oriented Flight Training (LOFT), which was graded Satisfactory without comment.

b. Analysis

Check Airmen and Captains who flew with First Officer Emmett within the 60 days prior to the accident praised First Officer Emmett's flying skills as "exceptional." His flight training record supports that conclusion. His flying record does not indicate any difficulty with making appropriate flight control inputs at the correct time. Nor does the record indicate any difficulty with orientation or controlling aircraft attitude. Throughout his seven-year career with USAir, First Officer Emmett, like Captain Germano, had successfully completed numerous training sessions and evaluations that included single engine maneuvering, steep turns, and other high task load events with significant potential for disorientation or confusion.

First Officer Emmett was fully trained and qualified to function as the First Officer aboard USAir Flight 427. His calm performance during the hydraulic failure incident only a month before the accident further demonstrates his flying proficiency and knowledge of proper crew coordination techniques. From his reported "exceptional" flying skills to his recent performance as a first officer, everything in First Officer Emmett's flying record indicates he was fully able to recognize, analyze, and successfully recover a normally functioning aircraft from the routine wake vortex encounter experienced by USAir Flight 427.

B. FLIGHT CREW PERFORMANCE

The investigation focused on two aspects of the performance of Captain Germano and First Officer Emmett during their encounter with wake vortex and the subsequent uncommanded full rudder deflection that caused this accident. The investigation examined whether the flight crew was the source of the full rudder movement and, whatever the source of the movement, whether the crew used proper recovery technique during the ensuing upset.

1. FLIGHT CREW CONTROL INPUTS

The Aircraft Performance Group concentrated its investigation on reconstructing the flight control inputs made during the accident sequence. Part of that effort included study of the effect of a Boeing 727's wake vortex on a Boeing 737. The Human Performance Group's efforts included study of the pilots' backgrounds and the actions of the pilots in the final moments of flight. Human Performance Group Chairman's Factual Report, Second Addendum, October 5, 1995, Exhibit 14X-A, at 2.

One question examined by these Groups was whether the flight crew commanded full-left rudder in reaction to the wake vortex then continued to command full-left rudder for 23 seconds while simultaneously attempting to overcome the rudder deflection with opposite aileron as the aircraft spiralled into the ground. The Aircraft Performance and Human Performance Groups investigated several areas in an attempt to determine if the full rudder deflection that caused this crash was commanded by the flight crew. Moreover, the Boeing Company provided the Human Performance Group and the Board with memoranda and a "contribution" intended to support the theory that Captain Germano and First Officer Emmett were so "startled" by a routine wake vortex encounter that they input full rudder and held it until the aircraft impacted the ground. As the following analysis shows, there is no evidence to support the theory that a pilot-commanded rudder deflection caused this accident.

a. Wake Vortex Encounter

i. Introduction

USAir Flight 427's wake vortex encounter has relevance to the accident investigation only to the extent that it caused a momentary rudder input (by the flight crew or through the yaw damper) which, due to an unknown mechanical malfunction, translated into a hardover or reversed rudder. The facts of the investigation do not support an inference that the continuous, full rudder deflection which occurred subsequent to USAir Flight 427's encounter with wake vortex was commanded by the flight crew.

ii. Factual Investigation

Radar data obtained during the investigation showed that at the time of the onset of the accident event, USAir Flight 427 was approximately 4.2 miles behind a Boeing 727 aircraft, Delta Flight 1083, which was flying approximately the same heading. The descent profiles of the two aircraft momentarily placed USAir Flight 427 slightly below the flight path flown by Delta 1083. As the accident event began, USAir Flight 427's FDR recorded slight changes in airspeed, attitude, and vertical "G" forces, indicating an encounter with the wake vortex of the preceding Boeing 727.

During its investigation of the USAir Flight 427 accident, the NTSB conducted flight tests in which a Boeing 737-300 was flown into the wake of a preceding Boeing 727 which had been configured with smoke generators to make the aircraft's wake vortices visible. Group Chairman's Report of Investigation -- Wake Vortex Flight Test, November 9, 1995, Exhibit 13X-A at 2. Among the purposes of the flights was to determine the aerodynamic effect of Boeing 727 wake vortices on a Boeing 737. Id.

Three of the pilots who participated in the wake vortex tests testified before the Board during its public hearings. Lester Berven is the Supervisory Flight Test Pilot in the Flight Test Branch of the FAA Aircraft Certification Office in Seattle, Washington. Testimony of Lester Berven, November 16, 1995 at 1966 (hereinafter, "Berven Tr."). He holds a Bachelor of Science degree in Aeronautical Engineering and has accumulated 7,000 total flying hours, of which approximately 3,500 are in certification or engineering flight test. Id. at 1967. He is rated in all Boeing aircraft except the B-707. Id. In his capacity as an FAA supervisory test pilot, he flies certification flights and supervises the activities of five other pilots. Id. He participated in the certification of the B-737-300 aircraft in 1984. Id. at 1968.

Michael Carriker is the Senior Engineering Project Pilot for the B-737 at the Boeing Company. Testimony of Michael Carriker, November 16, 1995 at 2083 (hereinafter, "Carriker Tr."). In that capacity, he contributes to new aircraft projects and continuing improvements. Id. at 2084. He holds a Bachelor of Science degree in Science and Aeronautical Engineering, was a Navy test pilot, and is rated in all current Boeing production aircraft. Id. He has amassed approximately 5,000 hours flight time.

Captain John Cox is a B-737 captain with USAir, and the Chairman of the Airline Pilots' Association Central Safety Committee at USAir. Testimony of Captain John M. Cox, November 16, 1995 at 2181 (hereinafter, "Cox Tr."). He has flown professionally for approximately 22 years. Id. at 2152. He has accumulated a total of 12,000 flight hours, of which approximately 8,000 have been in the B-737.

Each of these pilots described the flight test wake vortex encounters. Mr. Carriker testified that when encountering the B-727's wake vortex, the B-737 would react to the vortex

in the roll axis. Carriker Tr. at 2106. The encounters did not result in a large or sustained yaw or a large heading change. Id. at 2109; Berven Tr. at 2007. Each encounter resulted in a vertical G spike, followed by a rolling moment. Carriker Tr. at 2107. At no time did Mr. Carriker feel he was losing control of the aircraft during these wake vortex encounters. Id. at 2110.

Mr. Berven participated in the wake vortex test encounters conducted at four and three miles behind the B-727. Berven Tr. at 2003. He noted that the encounters with the vortex typically resulted in a 10° to 20° excursion in bank angle when the aircraft was being hand-flown or flown on the autopilot during the encounter. Id. at 1999. The maximum bank angle Mr. Berven experienced was 30°, and that was during a wake vortex encounter flown without any pilot or autopilot input to counter the vortex effects. Id. Mr. Berven found the autopilot did an effective job of controlling the aircraft during the wake vortex encounters. Id. at 2010. In encounters with the autopilot on, the aircraft typically did not roll more than ten degrees. Id. During none of the wake vortex encounters did Mr. Berven feel that the aircraft was out of control or even on the verge of being out of control. Id. at 2013.

Both Mr. Berven and Captain Cox stated that staying in the vortex was difficult because the dynamics of the aircraft and vortex resulted in the aircraft being "spit out" of the vortex rather rapidly. Berven Tr. at 2000; Cox Tr. at 2165. All three pilots noted that the average duration of an encounter with a wake vortex during the test was on the order of two seconds. Berven Tr. at 2000; Cox Tr. at 2165; Carriker Tr. at 2110. Mr. Carriker testified that it was possible to stay in the effect for up to three or four seconds, but only if the intent was to do so.

Carriker Tr. at 2110. Because the two wake vortices rotated in opposite directions, transitioning from one vortex to another during an encounter tended to correct the initial roll upset. Id.

Mr. Berven and Captain Cox also noted that wake vortex encounters are common in line flying. Berven Tr. at 2005; Cox Tr. at 2164. Captain Cox stated that wake vortex encounters occur on the order of two or three times during a three or four day trip. Cox Tr. at 2185. Captain Cox noted that the encounters he witnessed during the tests were representative of the wake vortex encounters he has experienced while flying the line. Cox Tr. at 2184. In both the tests and line flying, the maximum bank angle he typically has seen is 20 to 25 degrees. Cox Tr. at 2165-66. Captain Cox stated that wake vortex encounters during the test and during line flying are "not that disruptive a condition." Id. at 2164.

During the wake vortex encounters, the yaw damper of the B-737 was providing almost continuous input to the rudder, so much so that its input interfered with obtaining the desired data, leading the engineers to request that the pilots turn the yaw damper off during the encounters. Carriker Tr. at 2107. Id.

iii. Analysis

The radar, flight data recorder, and cockpit voice recorder data show that USAir Flight 427 almost certainly encountered the wake vortex of the preceding B-727. The radar data places USAir Flight 427 behind and slightly below the flight path of the B-727 at the time of the onset of the accident sequence. The FDR recorded excursions in roll, airspeed, and vertical "G" without an accompanying pitch attitude change. The CVR recorded thumps on the aircraft which later testing showed were consistent with the impact of a wake vortex on the fuselage of a B-737. However, the wake vortex encounter was not the cause of the accident.

The pilots who participated in the NTSB's wake vortex testing described the roll rates and magnitudes they encountered, and what they described was almost identical to the roll rates and magnitudes recorded on the USAir Flight 427 Flight Data Recorder. During the test, encounters with the wake vortex at approximately 4 miles behind the generating aircraft resulted in roll axis upsets of less than 25° when the autopilot was engaged, as it was on USAir Flight 427. Like USAir Flight 427's encounter with a wake vortex, these test encounters did not generate significant yawing moment.

The USAir Flight 427 FDR data shows that the aerodynamic reaction of the accident aircraft to its wake vortex encounter was identical to the routine wake vortex encounters described by Captain Cox and Mr. Berven. The maximum bank angle after the wake vortex encounter began, and before the onset of the uncommanded yaw event, was approximately 18°. Group Chairman's Report of Investigation, Flight Data Recorder Factual Report, November 28, 1994, Exhibit 10A, Attachment IV. Even the most extreme estimates of the roll rate the aircraft encountered during the wake vortex encounter was approximately 11° per second, but the aircraft rolled less than 10° at that rate. See, Boeing Contribution to the USAir Flight 427 Accident Investigation Board, September 25, 1996, at 4-6. Until the onset of the full-left rudder, the maximum yaw rate during the wake vortex encounter was negligible. Id. Until the onset of the full-left rudder, bank angle changes during the wake vortex encounter, though rapid, were slight. The FDR data clearly show the USAir Flight 427 wake vortex encounter was nothing out of the ordinary. It was virtually identical to the types of wake vortex encounters that are common in line flying.

Such wake vortex encounters are not unusual in line flying, and any initial surprise experienced by the pilots on encountering a wake vortex quickly changes to recognition, analysis, and recovery. Cox Tr. at 2170. Captain Cox, the one pilot with extensive line flying experience who flew these tests, stated the vortex encounters are just not that disruptive. The crew of USAir Flight 427 had a combined total of nearly 8,000 hours of Boeing 737 time, and over 14,000 hours as airline pilots for USAir. Captain Germano had flown the line at USAir for over 13 years, and First Officer Emmett had flown the line for seven years. Each had additional aviation experience prior to their USAir employment. A wake vortex encounter would have been routine for such highly-experienced crew members.

Listening to the pilots' reactions on USAir Flight 427's Cockpit Voice Recorder tape also reflects that these pilots were not so startled by this routine wake vortex encounter that they applied incorrect flight control inputs and held them. After the pilots' initial reaction ("Sheez," "Zuh"), the only comment either pilot made before the full-left rudder began is the Captain's comment, "Whoa." His voice on the CVR is neither startled nor panicked; rather, the statement is nothing more than commentary. As the event progressed from a wake vortex encounter to an uncommanded rudder deflection or reversal, the voices of the pilots understandably express rising concern over the performance of the aircraft. However, an expletive spoken by First Officer Emmett some four seconds after the onset of the uncommanded rudder deflection is made in a calm, but concerned, tone. The evidence shows that these pilots were not so startled by this routine wake vortex encounter that they incorrectly applied full-left rudder, countered it with full-right aileron, then held these full cross-controlled positions for 23 seconds while spiralling toward the ground.

Boeing's February 28, 1996 memorandum to the Chairman of the Human Performance Group invites a chain of inferences from 44 anecdotal aircraft incident reports concerning wake vortex encounters. The first inference invited by this memorandum is that flight crews are commonly so "startled" by encounters with wake vortex that they input improper flight controls or put in proper flight controls but forget to take them out. Most of the encounters cited were behind "heavy" category aircraft, or at short range, or at low altitude, or under some combination of these circumstances. It should also be noted that in the 44 reports of wake vortex encounters cited in the Boeing memorandum, only two of the events even arguably included an incorrect application of flight controls by a crew member. Neither of these two incident reports indicate the crew held the incorrect input for more than a few seconds.

Relying on the same data, Boeing's September 25, 1996 "contribution" to the Board concludes that the crew of USAir Flight 427 were "startled" by their wake vortex encounter, leading to the incorrect application of full-left rudder and full-right aileron until the aircraft spiralled into the ground 23 seconds later. In support, the "contribution" breaks the movements of USAir Flight 427 during the wake vortex encounter into tenth-of-a-second increments and suggests that the roll accelerations experienced were so far above what the crew would normally experience that they could not cope. However, the bank angle changes that occurred at these rates were sometimes as small as two or three degrees and never more than 10 degrees. They were, in essence, momentary jolts rather than dramatic, sustained accelerations.

USAir Flight 427 experienced a routine wake vortex encounter that resulted in several rapid, small, momentary roll angle changes. The accident aircraft's roll rates and accelerations were similar to those documented during the NTSB's wake vortex testing. See, Group

Chairman's Report of Investigation, Wake Vortex Flight Test, Exhibit 13X-A, November 9, 1995 at 27A - 34B. USAir Flight 427's encounter with wake vortex resulted in the type of "bounce" or "light to moderate turbulence" described by the pilots who flew the wake vortex test. Carriker Tr. at 2110; Berven Tr. at 2007. Such encounters are quite common in line flying. Cox Tr. at 2185. Given Captain Germano's and First Officer Emmett's experience, these relatively benign motions resulting from a routine wake vortex encounter would not have led to an extreme misapplication of flight controls.

The ultimate inference the Boeing contribution would have the Board draw is that the crew of USAir Flight 427 applied full-left rudder during the wake vortex encounter and held it there while applying fully cross-controlled ailerons until impact some 23 seconds later. However, the facts revealed during this investigation simply do not support an inference that the crew of USAir Flight 427 reacted to the wake vortex encounter by incorrectly applying flight control inputs. Wake vortex encounters are common events to line pilots and are relatively benign, seldom resulting in more of an upset than 25° of bank, as was the case with USAir Flight 427. Line pilots routinely deal with recoveries from such encounters. Few, if any, of the reported wake vortex encounters cited to support the inference indicate an incorrect application of flight controls, inadvertent or otherwise. Similarly, none indicate any instance in which correct controls were applied then inadvertently held after they were no longer needed. Whatever the cause of the rudder deflection that led to the crash of USAir Flight 427, there is no evidence to suggest it was an incorrect or inadvertent pilot input brought on because the crew reacted incorrectly to a wake vortex encounter.

B. Disorientation and Vestibular Effects

i. Introduction

The Human Performance Group investigated the possibility that the crew of USAir Flight 427 may have experienced spatial disorientation during the wake vortex encounter, causing them to misapply the flight controls. The evidence discovered by the investigation shows the pilots were not disoriented.

ii. Factual Investigation

Spatial disorientation is usually associated with degraded out-of-cockpit vision, coupled with changes in aircraft accelerations that are either sudden and violent or subtle and gradual. Letter from Malcolm M. Cohen, Ph.D. to Malcolm Brenner, Ph.D., September 21, 1995, at 1 (hereinafter, "Cohen Report"). The Human Performance Group asked Malcolm M. Cohen, Ph.D., NASA Ames Research Center, to examine relevant information from the accident investigation in an attempt to determine if disorientation or vestibular effects could have played a role in the accident. Human Performance Group Chairman's Factual Report, Second Addendum, October 5, 1995, Exhibit 14X-A, at 6. Dr. Cohen underwent repeated simulations of the USAir Flight 427 event in the NASA Vertical Motion Simulator, using large physical motions to produce a high fidelity reconstruction of the event. Id.

Dr. Cohen concluded that the accident scenario did not contain evidence of the factors normally associated with disorientation. Cohen Report at 1. The accident occurred during daylight hours in clear air with good visibility and a clearly defined horizon. Human Performance Group Factual Report, Exhibit 14X-A, at 6. The motion of the aircraft after the onset of the accident event did not exhibit the types of accelerations that would be conducive to

disorientation. Cohen Report at 2. The motions of the aircraft as the event progressed were relatively gradual and nearly continuous. Id. The pilots' comments indicated they were fully aware of their trajectory, but they were unable to change it. Id. This evidence is consistent with the testimony of two pilots who participated in the wake vortex testing, who stated that the wake vortex encounter is not a disorienting event. Cox Tr. at 2170-71; Carriker Tr. at 2111.

iii. Analysis

Dr. Cohen's analysis indicates the crew of USAir Flight 427 were not disoriented by the wake vortex encounter that marked the beginning of the accident sequence. The weather was clear and the horizon distinct. The change in aircraft attitude happened gradually and continuously, and the pilots' comments indicate they were aware of the change but could do nothing about it. This simply was not an event that involved the sudden placement of an aircraft in an extreme attitude, nor was it a case where subtle changes in aircraft attitude went unnoticed by the crew until an extreme attitude had developed. Pilots who participated in the NTSB's wake vortex testing testified that encountering a wake vortex is not a disorienting experience, and the facts developed during the investigation indicate the pilots were aware of the attitude of the aircraft at all times during the accident sequence. Therefore, disorientation was not a factor in causing this accident.

c. Speech Patterns

i. Introduction

The Human Performance Group investigated the speech patterns of the USAir Flight 427 flight crew captured on the Cockpit Voice Recorder. The investigation revealed, not surprisingly, that the pilots exhibited rising stress as the accident event progressed. The analysis also showed excellent crew coordination before and during the event and that First Officer Emmett was physically flying the aircraft.

ii. Factual Investigation

The Human Performance Group studied the speech patterns of the pilots using the Cockpit Voice Recorder tape. Three consultants provided input to the Group: an exercise physiologist who focused on breathing patterns and physical exertion; a NASA Human Performance Researcher who focused on intra-cockpit communication; and a Russian acoustics analyst who focused on psychological stress and physical effort. Speech Examination Factual Report, May 5, 1997 at 5.

There was no audible grunting or straining indicative of physical exertion heard from Captain Germano before or immediately after the onset of the accident sequence. Letter from Scott Meyer, Ph.D. to Malcolm Brenner, Ph.D., March 29, 1996, ¶ 7 (hereinafter, "Meyer Report"). Captain Germano's speech patterns indicate he did not exhibit signs of physical exertion until about 4.8 seconds prior to the aircraft's impact with the ground. This straining may have been as a result of "G" forces on the aircraft or of his participation in manipulating the flight controls. Letter from Alfred S. Belan to Malcolm Brenner, Ph.D., March 26, 1997, at 3 (hereinafter, "Belan Report").

Shortly after the onset of the accident sequence First Officer Emmett made several rapid grunting exhalations. Meyer Report at ¶ 5; Belan Report at 4. In addition, analysis of the USAir Flight 427 Cockpit Voice Recorder tape indicated seven occasions after the accident sequence began in which First Officer Emmett keyed the yoke-mounted radio microphone switch. Id. at 4. Human Performance Group Chairman's Factual Report, Second Addendum, October 5, 1995, Exhibit 14X-A, at 4. During none of these times did First Officer Emmett direct conversation outside the aircraft. Conversely, Captain Germano keyed his microphone switch only one time during the accident sequence, and that was to make an emergency transmission directed to the air traffic control agency. Id.

Analysis of the intra-cockpit communications indicated there was no reluctance of the crew to seek and incorporate information from each other, and the level of coordination and communication was appropriate. Letter from Barbara G. Kanki, Ph.D. to Malcolm Brenner, Ph.D., December 2, 1996 at 3. During the accident sequence, the Captain's comments ("Hang on"; "What the hell is this?"; "Pull") were mainly limited to commands and attempts to evaluate the situation. Belan Report at 3.

iii. Analysis

Analysis of the CVR and air traffic control tapes shows that First Officer Emmett was the pilot flying the aircraft up to the time of the wake vortex encounter. After the encounter, there was no indication on the CVR of a change of aircraft control. First Officer Emmett's speech patterns at the beginning of the accident sequence showed forcible exhalations indicating physical exertion. This evidence suggests First Officer Emmett was straining while manipulating the aircraft's controls. Meyer Report at 2. Conversely, the lack of such straining in Captain

Germano's speech patterns suggests Captain Germano was not manipulating the controls. Further, First Officer Emmett keyed his yoke-mounted microphone switch seven times during the accident sequence without making a deliberate transmission. Such inadvertent microphone keying can be an indicator that a pilot is manipulating the control wheel. Human Performance Group Factual Report, Second Addendum, Exhibit 14X-A at 3. Conversely, Captain Germano keyed his microphone switch but once, and that was done in an attempt to notify air traffic control of USAir Flight 427's emergency. Id. at 4. These facts strongly infer that First Officer Emmett was manipulating the flight controls during the wake vortex encounter and the subsequent flight control malfunction and that Captain Germano was not.

Analysis of the CVR also shows the crew used good crew coordination throughout the accident sequence. In fact, analysis of the entire 30-minute CVR tape showed good cockpit resource management throughout the last half hour of the flight. During the time before the onset of the accident sequence, each pilot sought and incorporated information from the other, and the level of communication and coordination was appropriate for the task. Captain Germano's statements during the accident sequence were in the nature of commands and attempts to evaluate the situation and were proper in that context.

The Boeing February 28, 1996 memorandum to the Chairman of the Human Performance Group and the September 25, 1996 "contribution" to the Board suggest that the crew was startled by the wake vortex encounter, perhaps leading to both crew members manipulating the controls during the wake vortex encounter and subsequent flight control malfunction. The inference is that the pilots may have been making contrary control inputs. The inference is not supported by the evidence, however. The evidence indicates that the pilots were not startled by this

routine wake vortex encounter and reacted properly to it. In addition, the speech analysis evidence shows that First Officer Emmett was in physical control of the aircraft during both the wake vortex encounter and the subsequent attempt to recover from the uncommanded rudder deflection. The evidence is also clear that while First Officer Emmett flew the aircraft, Captain Germano properly provided direction and attempted to analyze the situation. This evidence indicates the pilots performed their proper duties throughout the accident sequence, and there was no confusion about which pilot was manipulating the flight controls.

d. Rudder Pedal Damage Patterns

i. Introduction

After admitting there was insufficient pathological information on which to base an opinion, the Deputy Medical Examiner for the Armed Forces Institute of Pathology provided an opinion to the Human Performance Group Chairman concerning the forces being applied to the rudder pedals by the pilots at impact. Because the metallurgical evidence currently available is at best ambiguous, and the pathology expert was not qualified to render an opinion on this ambiguous metallurgical data, no conclusions can or should be drawn concerning the forces being applied to the rudder pedals at impact. In fact, to the extent a conclusion can be drawn from the metallurgical data, it is that a substantial amount of force was applied to all four rudder pedals and/or their mounting structures at some point during the impact sequence.

ii. Factual Investigation

Metallurgical examination of the pilots' rudder pedals and mounting hardware showed that all four of the pilots' rudder pedals bent forward during the impact sequence. Both pilots' right rudder pedals bent forward 20° and remained attached to their mounting pivot lugs.

Captain Germano's left rudder pedal sheared from its mounting pivot lug after also bending forward 20°. First Officer Emmett's left rudder pedal sheared from its mounting pivot lug after the pedal had bent forward 5°. System Group Chairman's Factual Report of Investigation, December 21, 1994, Exhibit 9A at 40; Metallurgist's Factual Report No. 95-43, December 27, 1994, Exhibit 9B, at 1. The NTSB's metallurgical analysis did not make any findings as to pressure being applied to the pedals at impact.

Dr. David W. Hause, Deputy Medical Examiner for the Armed Forces Institute of Pathology, reported that while determination of rudder pedal position can be inferred from the study of the pilots' remains, the extent of body disruption, quantity of recovered remains, and incomplete reassociation of the remains in this case made an analysis based on forensic pathology principles impossible. Letter from David W. Hause to Malcolm Brenner, Ph.D., January 22, 1996, Attachment 8 to Human Performance Group Chairman's Factual Report of Investigation, Fourth Addendum.

Notwithstanding this lack of information, Dr. Hause went on to provide an opinion to the Human Performance Group in which he "infer[red] the possibility" that both pilots were "symmetrically applying pressure to their respective left rudder pedals at the time of ground impact." Id. He based his opinion on the NTSB's metallurgical analysis of the pedals and attaching hardware. Id. Dr. Hause claimed he was able to "infer the possibility" that at impact both pilots were "symmetrically applying" "strong pressure" to the pedals with the "left knee locked" and "the majority of body weight concentrated on the left foot." Id.

iii. Analysis

There is no reason, based on the investigation record, to question the expertise of Dr. Hause as a pathologist. Indeed, Dr. Hause properly rendered an expert opinion in the field of pathology when he found there was insufficient medical evidence on which to determine rudder pressure being applied at the time of impact. Dr. Hause is not, however, an expert in metallurgy and is patently unqualified to render an expert opinion based upon metallurgical evidence. Since Dr. Hause based his inferences on data outside his field of expertise, his conclusions should be disregarded.

Furthermore, the shear patterns of the rudder pedals on the accident aircraft are at best inconclusive as to the pressure being applied to them at the time of impact or at any other point during the impact sequence. The fracture patterns of the rudder pedal attachment hardware from USAir Flight 427 do not suggest an application of force by the pilots to any of the rudder pedals. Captain Germano's left and right pedals bent forward an equal amount (20°), but the left one sheared off while the right one did not. There is nothing in this pattern to suggest more pressure on one pedal than the other. First Officer Emmett's right pedal also bent forward 20° and did not shear off, while his left pedal bent forward less than 5° before shearing. No metallurgist has provided an opinion as to the significance of these bending and shearing patterns, but they would not seem to indicate that one pedal was under greater pressure than the other at impact, although they may provide some indication as to the relative strength and flexibility of the attachment hardware. In fact, to the extent a conclusion can be drawn from the metallurgical data, it is that a substantial amount of force was applied to all four rudder pedals and/or their mounting structures at some point during the impact sequence.

It is also significant that the aircraft impacted the ground nose first at 261 knots, approximately 80° nose down, in 60° of left bank, and in a significant sideslip. A great deal of aircraft structure undoubtedly impacted the rudder pedals with enormous force as the aircraft telescoped on impact. Given the left bank and sideslip, it is also probable that the force vectors would focus more on the left side of the aircraft.

Dr. Hause's inferences are nothing more than unfounded speculation by an unqualified witness based on ambiguous and inconclusive data. Because the metallurgical analysis currently available is at best ambiguous, and Dr. Hause was not qualified to render an opinion on this data, no conclusions can or should be drawn concerning the forces being applied to the rudder pedals at impact.

2. FLIGHT CREW RESPONSE TO FULL-LEFT RUDDER DEFLECTION

This section addresses the flight crew's response to the full-left rudder deflection experienced by the accident aircraft. Because the aircraft was at or near its "crossover speed" (a speed which was not communicated to USAir until after this accident), and there was no known reason for the flight crew to maintain or increase airspeed by descending, the aircraft quickly departed from controlled flight notwithstanding proper efforts by the flight crew to maintain control. While unusual attitude training is useful and appropriate for airline flight crews, it would not have affected the outcome of this accident given the full-left rudder deflection and the accident aircraft's crossover speed.

a. Crossover Speed

i. Introduction

Post-accident flight tests conducted in a Boeing 737-300 aircraft revealed that 190 knots indicated airspeed ("KIAS") was at or very near the "crossover speed" for the weight and configuration of USAir Flight 427. Below that speed, ailerons and spoilers are insufficient to stop the roll induced by a full rudder deflection. Termed the "crossover speed," this information was not provided to USAir or the airline industry prior to this accident.

When the full-left rudder movement occurred, USAir 427's flight crew applied lateral controls to counteract the roll and increased aft yoke pressure to maintain altitude while they analyzed and corrected the problem. Although this was proper technique, these actions quickly placed the aircraft in a position from which recovery was impossible. Unknown to the flight crew and the industry, the aircraft's crossover speed required an increase in airspeed, and a corresponding loss of altitude, to accomplish a recovery.

ii. Factual Investigation

At the beginning of the accident sequence, USAir Flight 427 was in level flight at 190 KIAS, as directed by Air Traffic Control. Specialist's Factual Report of Investigation, Cockpit Voice Recorder, October 5, 1994, Exhibit 12A at 24. Upon acknowledging this speed, the crew of USAir Flight 427 selected Flaps 1. Id. This configuration was proper according to both the manufacturer's and USAir's maneuvering speed schedules.

Early in the investigation, the Aircraft Performance Group conducted tests in the Boeing Multipurpose Engineering Cab ("MCAB") simulator. These tests indicated that the B-737's

ailerons and spoilers provided lateral control authority sufficient to counteract a fully-deflected rudder and maintain control of the aircraft.

On October 20, 1994, the FAA began a Critical Design Review of the Boeing 737 flight control system, with emphasis on the lateral and directional flight controls. Boeing 737 Flight Control System Critical Design Review Report, May 3, 1995 at 1. The CDR team concluded that a number of possible failure modes existed in the B-737 which could result in loss of rudder control and subsequent uncommanded, sustained, full rudder deflection or reversal. Id. at 16. The CDR team concluded that because of this potential, lateral flight controls must be "fully available and powerful enough to rapidly counter the rudder and prevent entrance into a hazardous flight condition." Id.

During its study, the CDR group conducted tests in the Boeing MCAB simulator. Id. at 11. These tests provided further data on the aircraft's controllability with a full, sustained rudder deflection, including rudder hardovers. Id. at 12. The group found that the lateral control system could overcome the roll induced by a hardover rudder, except at the 190 KIAS/Flaps 1 data point. Id. At this point, recovery was possible but was very slow and required prompt, precise pilot control of pitch and airspeed to preclude entering an inverted attitude. Id. For example, one of the simulator recoveries from a rudder hardover at the 190 KIAS/Flaps 1 configuration required two separate descents to gain airspeed, and 35 seconds passed before the simulator was brought under control. Id. at A-19. The report stated that during this exercise, "recovery from yaw was in doubt." Id. The amount of altitude lost was not reported.

During September and October 1995, the NTSB, with the participation of USAir, Boeing, ALPA, the FAA, and NASA, conducted flight tests using a Boeing 737-300 aircraft provided by USAir. One purpose of these flight tests was to verify the accuracy of the Boeing MCAB simulator's B-737 flight parameters. Berven Tr. at 1973. One data point during the flight test was designed to determine the aileron and spoiler deflection required to counteract the roll caused by a full rudder deflection at various airspeeds and flap settings. Id. at 1972. The flight tests and later engineering analyses revealed that for a B-737 aircraft in the same configuration as USAir Flight 427, there was a "crossover speed" near 190 knots. "Crossover Speed" is an engineering term that refers to the speed at which one set of flight controls exactly offsets the effects of another set of flight controls, in this case ailerons and spoilers versus the rudder. Above or below that speed, one set of flight controls is predominant. Id. at 1980. During the test flights, it was discovered that at speeds near 190 knots in level, steady-heading side slips, lateral controls (ailerons and spoilers) were sometimes insufficient to stop aircraft roll induced by a full rudder deflection. Cox TR at 2161. At the time of the USAir 427 accident, airline pilots were not trained in or aware of the concept of "crossover speeds." Cox Tr. at 2191-2. Neither the term nor the concept appeared in materials the manufacturer provided to the airline industry.

The flight tests also revealed that rudder travel in the B-737 was greater than that programmed into the Boeing MCAB simulator; that is, the aircraft was shown to possess more rudder authority than was programmed into the simulator for the 190 KIAS/Flaps 1 data point. Because of these findings, the MCAB simulator was modified to more accurately reflect the rudder authority actually available in the aircraft.

After these modifications, Mr. Berven attempted recoveries in Boeing's MCAB simulator from full dynamic rudder deflections. Id. at 2021. After the rudder deflection, Mr. Berven delayed three seconds to simulate a pilot's recognition time, then started a recovery. If he disregarded altitude loss and allowed airspeed to increase, the roll typically could be reversed at a 75° bank angle. When he attempted to keep the aircraft level and maintain 190 knots, the aircraft could not be returned to wings level flight -- it continued to spiral in a 70° bank. Id. at 2022. If he allowed the airspeed to accelerate to above 200 knots, however, the aircraft would begin to recover. Id.

Neither Mr. Berven nor Captain Cox believed a typical airline flight crew would have attempted to deal with a rudder hardover -- assuming they knew such a malfunction could occur and had a way to recognize it -- by descending to increase airspeed and improve aileron/spoiler effectiveness. Id. at 2036; Cox Tr. at 2190. Instead, when a pilot is faced with a flight control malfunction, he or she would instinctively preserve altitude while attempting to resolve the problem. Berven Tr. at 2037. In fact, prevailing unusual attitude recovery techniques call for aft yoke pressure when recovering from a nose low attitude with less than 60-90° of bank.

In December 1995, USAir increased by 10 knots its Boeing 737 minimum maneuvering airspeeds for the flaps 1, 5, and 10 settings at gross weights at and below 117,000 pounds. Boeing stated it had "no technical objection" to these changes, which cleared the way for USAir to implement the new speeds. Some, but not all operators have followed USAir's action. Boeing has not affirmatively recommended the changes, stating that the increase does not provide significant technical benefits to directional control.

USAir also worked to develop a procedure for handling a hardover rudder. Among other things, the procedure calls for the flight crew to maintain an airspeed at or above the new maneuvering speed, even if altitude is lost in the process. That procedure was ultimately incorporated into an FAA Airworthiness Directive and is now a part of the Boeing 737 Pilot's Handbook.

In June 1997, Boeing provided the NTSB with charts purporting to depict the effect of bank angle on crossover speeds. This data was not developed as part of the NTSB investigation and the underlying data and formulae were not provided to the NTSB. While the charts contain certain anomalies, they do indicate that B-737 crossover speeds increase with bank angle or, more correctly, with angle of attack or G loading.

iii. Analysis

At the time the accident sequence began, USAir Flight 427 was cruising at an assigned altitude and airspeed of 6,000 feet and 190 KIAS. Commensurate with the manufacturer's flap maneuvering speed schedule and USAir's B-737-300/400 Pilot's Handbook, the crew had configured the aircraft with Flaps 1.

Post-accident flight tests conducted in a Boeing 737-300 aircraft showed conclusively that 190 KIAS was at or very near the "crossover speed" for the weight and configuration of USAir Flight 427. At this speed, ailerons and spoilers were sometimes insufficient to stop the roll induced by a full rudder deflection. Charts Boeing provided to the NTSB in June 1997 suggest that B-737 crossover speeds increase with bank angle (actually angle of attack or G loading).

Initial investigation efforts in the Boeing MCAB simulator indicated the aircraft could be recovered from a hardover rudder at 190 KIAS/Flaps 1. However, this testing occurred before the simulator was modified to reflect the aircraft's actual rudder authority. Similarly, the FAA Critical Design Review team found recovery from a full rudder hardover at 190 KIAS/Flaps 1 to be very difficult in the MCAB simulator. These tests also occurred before the simulator had been modified to reflect actual B-737 rudder authority. From the CDR team's description of the recovery attempts, it is clear that more rudder authority would have made a successful recovery nearly impossible.

After the Boeing MCAB simulator was modified to reflect the actual rudder effectiveness found in the aircraft, the FAA's Mr. Berven, one of the pilots who flew the test flights, experimented with sudden hardover rudder deflections in the simulator. He concluded that if a B-737-300 aircraft cruising at 190 knots with Flaps 1 encountered a hardover rudder, recovery was impossible if the pilot attempted to maintain altitude. Recovery under those conditions was possible only if the pilot descended to gain airspeed, which decreases rudder effectiveness and increases aileron/spoiler authority enough to overcome the roll. However, he also stated that airline flight crews were unlikely to take such action, as their natural reaction would be to maintain altitude, particularly while analyzing a control problem.

The manufacturer's pilot handbook for the B-737 did not contain a procedure for recovering from a hardover rudder. Moreover, the airline industry was not aware that the manufacturer's recommended maneuvering speed for USAir Flight 427's configuration and weight placed the aircraft at or very near the speed at which full lateral controls were insufficient to stop the roll induced by a dynamic hardover rudder or rudder reversal. Indeed, at the time

of the USAir 427 accident, the manufacturer had not informed the airline industry of the "crossover speed" concept.

While unknowingly cruising at or near the crossover speed for their weight and configuration, the crew of USAir Flight 427 encountered the wake vortex of a preceding aircraft. The Flight Data Recorder from USAir Flight 427 indicates a full-left rudder movement occurred approximately four seconds after the wake vortex encounter began. At that time, the aircraft was in approximately 18° left bank and maintaining level flight. This uncommanded, dynamic, full-left rudder movement occurred when the aircraft was at or below the "crossover speed" and an uncontrollable yaw and roll to the left resulted. The crew's training and piloting sense dictated that they should maintain altitude while analyzing and correcting the problem, in order to preserve maneuvering room and available time in which to effect a recovery. At the onset of the rudder movement, the crew took reasonable action to counteract the roll with lateral controls while attempting to maintain altitude as they dealt with the situation. Unknown to the crew, these actions quickly placed the aircraft in a position from which recovery was impossible.

b. Unusual Attitude Training

i. Introduction

US Airways believes unusual attitude training is useful and appropriate for airline flight crews. US Airways has always incorporated unusual attitude maneuvers, concepts and techniques into its pilot training programs. In addition, all USAir pilots received unusual attitude recognition and recovery a number of times prior to becoming airline pilots. In certain circumstances, unusual attitude recognition and recovery techniques can be critical to the safety of flight. However, no amount of unusual attitude training could have prevented this accident.

The full-left rudder deflection combined with the then-unknown crossover speed of the B-737 aircraft prevented the recovery of Flight 427 notwithstanding the flight crew's application of proper recovery techniques.

ii. Factual Investigation

The comments made by the pilots indicate they were fully aware of the aircraft's attitude, but were unable to change it. Cohen Report at 2. Captain Cox thought unusual attitude training would not be pertinent if the unusual attitude resulted from a deflected flight control combined with a lack of full authority over all three axes of flight. Cox Tr. at 2177.

Additional training in recovery from high bank angle, nose low attitudes has been considered and implemented by several operators, including US Airways. American Airlines pilots are taught that when bank angle is less than 60° in a nose low unusual attitude, the pilot should increase back pressure on the yoke. February 28, 1996 letter from Curt Graeber and Mike Carriker to Malcolm Brenner, at Part II, No. 17. Flight Safety International recommends that during a nose low recovery the pilot should increase back pressure immediately if the bank angle is less than 90°. Id. at 28. US Airways' Selected Events Training program teaches pilots to apply back pressure in a high bank, nose low recovery after the bank is reduced to less than 60°.

iii. Analysis

All unusual attitude training assumes proper functioning of flight controls. Here, the rudder moved to an uncommanded full deflection at an airspeed which precluded recovery by use of lateral controls. Unusual attitude training was, therefore, completely irrelevant because

the aircraft was not responding in a way that allowed recovery by application of unusual attitude recovery techniques.

In any event, the actions of the crew of USAir Flight 427 conformed with unusual attitude recovery procedures, including those published after the accident. As the uncommanded rudder movement began, the aircraft yawed and rolled to the left and the nose began to drop. With a nose low, left bank attitude, the proper procedure is to counter the roll with opposite aileron/spoiler and increase back pressure on the yoke to reduce altitude loss, unless the bank angle exceeds 60-90 degrees. This is exactly what the USAir 427 flight crew did. As the bank angle continued to increase, and the nose continued to drop, the flight crew disconnected the autopilot, added additional right aileron/spoiler, and increased back pressure on yoke. This, too, is consistent with proper procedure. The aircraft reached 60° of bank just over 5 seconds after the uncommanded rudder movement began, approximately 1½ seconds before the aircraft stalled. At 60° of bank, the flight crew had applied approximately 2/3 of the available aft yoke authority and full-right aileron/spoiler, again as appropriate under the circumstances. The aircraft stalled at approximately 70° of bank, approximately seven seconds after the full-left rudder movement began.

In hindsight, it can be said that the proper procedure would have been to increase airspeed by descending until the aircraft accelerated through the crossover speed. This is not, however, an unusual attitude recovery technique. It is a technique to recover from a B-737 hardover rudder or rudder reversal. It is also a technique that is at odds with unusual attitude recovery procedures and natural piloting instincts.

Because proper unusual attitude recognition and recovery techniques were followed, and previously unknown factors were at work on the aircraft, additional unusual attitude training would not have prevented this accident.

Under any circumstances then known to the airline industry, the actions of the crew of USAir Flight 427 were reasonable and correct. Unfortunately, the crew encountered an uncommanded full rudder deflection at or below the crossover speed and entered a flight regime wholly unknown at the time to this crew or the airline industry. Under these extraordinary circumstances, the crew's application of the correct flight control inputs in an attempt to recover from an uncommanded yaw/roll/descent quickly placed the aircraft in an unrecoverable situation.

The actions of this crew cannot be judged with the benefit of 20/20 hindsight which is itself based on over three years of intense investigation and analysis. This crew had seven seconds, at most, in which to recognize, analyze, and recover from a previously-unknown malfunction. Worse yet, this crew faced the malfunction in a flight regime where recovery was impossible unless the crew reacted in a way that was contrary to their training and natural piloting instincts.

V. CONCLUSIONS

A. FINDINGS

1. The Captain and First Officer were trained, certificated and qualified for the flight in accordance with applicable regulations.

2. Nothing in the flight crew's background suggests they would have had problems with disorientation or control of the accident aircraft.

3. The flight crew's performance was not affected by illness, fatigue, or personal or professional problems.

4. The aircraft was properly maintained in accordance with applicable regulations. Inspections of the rudder control system required by AD 94-01-07 had been correctly accomplished in a timely manner.

5. It was daylight and the weather was clear with a distinct horizon at the time of the accident.

6. The accident aircraft's speed and configuration at the beginning of the accident event complied with the manufacturer's and operator's maneuvering speed schedules.

7. At the beginning of the accident event, the aircraft was at or below the "crossover speed," which is the speed below which lateral flight control authority is insufficient to counter the roll induced by a full rudder deflection.

8. The manufacturer did not advise the operator, prior to this accident, that there were speeds below which B-737 lateral flight control authority is insufficient to counter the roll induced by a full rudder deflection.

9. The manufacturer's published maneuvering speeds for some weights and configurations of the Boeing 737 were too slow and did not provide sufficient airspeed margins to allow recovery from an uncommanded, fully deflected rudder or rudder reversal.

10. The accident aircraft's rudder moved uncommanded or reversed to the full-left position.

11. At the onset of the full rudder movement, the accident aircraft's speed was at or below the "crossover" speed.

12. The manufacturer did not provide the operator, prior to this accident, with an emergency procedure for recovery of a Boeing 737 from an uncommanded, full rudder deflection or rudder reversal.

13. Based on information known to them at the time, the flight crew reacted correctly to the uncommanded, full rudder deflection or rudder reversal and resultant left roll by selecting opposite aileron and attempting to maintain altitude.

14. After the onset of the full rudder movement, decreasing airspeed, increasing bank angle, and increasing aerodynamic loads kept the aircraft's speed below the "crossover" speed.

15. With an uncommanded, fully-deflected rudder or rudder reversal and the aircraft below the "crossover" speed, recovery through techniques known at the time was not possible.

B. PROBABLE CAUSE

The probable cause of this accident was an uncommanded, full rudder deflection or rudder reversal that placed the aircraft in a flight regime from which recovery was not possible using known recovery procedures.

A contributing cause of this accident was the manufacturer's failure to advise operators that there was a speed below which the aircraft's lateral control authority was insufficient to counteract a full rudder deflection.

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