Runway Side Excursion During Attempted Takeoff in Strong and Gusty Crosswind Conditions
Continental Airlines Flight 1404
Boeing 737-500, N18611
Denver, Colorado
December 20, 2008

Accident Report

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National Transportation Safety Board

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Aviation Accident Report

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National
Transportation
Safety Board

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2010. ***Runway Side Excursion During Attempted Takeoff in Strong and Gusty Crosswind Conditions, Continental Airlines Flight 1404, Boeing 737-500, N18611, Denver, Colorado, December 20, 2008*****. Aviation Accident Report/AAR-10/04. Washington, DC.**

Abstract: This report describes an accident that occurred on December 20, 2008, about 1818 mountain standard time, in which Continental Airlines flight 1404, a Boeing 737-500, N18611, departed the left side of runway 34R during takeoff from Denver International Airport, Denver, Colorado. A postcrash fire ensued. The captain and 5 of the 110 passengers were seriously injured; the first officer, 2 cabin crewmembers, and 38 passengers received minor injuries; and 1 cabin crewmember and 67 passengers (3 of whom were lap-held children) were uninjured. The airplane was substantially damaged.

The safety issues discussed in this report include the pilots' actions, training, and experience; air traffic controllers' obtaining and disseminating wind information; runway selection and use; crosswind training; simulator modeling; crosswind guidelines and limitations; certification and inspection of crew seats; and galley latches.

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Abbreviations

AC	advisory circular
agl	above ground level
ALP	airport layout plan
ALPA	Air Line Pilots Association
AMASS	airport movement area safety system
ARFF	aircraft rescue and firefighting
ASOS	automated surface observing system
ATC	air traffic control
ATCT	air traffic control tower
ATIS	airport terminal information service
ATP	airline transport pilot
AW	airport wind
CAM	cockpit area microphone
CFR	*Code of Federal Regulations*
cg	center of gravity
CIC	controller-in-charge
COS	Colorado Springs Municipal Airport
CVR	cockpit voice recorder
DEN	Denver International Airport
E/E	electrical equipment compartment
EST	eastern standard time
FAA	Federal Aviation Administration

FDR	flight data recorder
FFS	full-flight simulator
G	One G is equivalent to the acceleration caused by the Earth's gravity (32.174 feet per second squared)
Hg	Mercury
IAH	George Bush Intercontinental Airport
ITWS	Integrated Terminal Weather System
LLWAS	low-level windshear alert system
LLWAS-NE^{++}	low-level windshear alert system network expansion rehost system
MAC	mean aerodynamic chord
M-CAB	multi-purpose engineering cab
MST	mountain standard time
NAS	National Airspace System
NATCA	National Air Traffic Controllers Association
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NPRM	notice of proposed rulemaking
NTSB	National Transportation Safety Board
NWS	National Weather Service
PHL	Philadelphia International Airport
PIREP	pilot report
PST	Pacific standard time
QAR	quick access recorder
RBDT	ribbon display terminal
SB	service bulletin

SFO	San Francisco International Airport
S/N	serial number
SOP	standard operating procedures
SNECMA	Société Nationale d'Étude et de Construction de Moteurs d'Aviation
TDWR	Terminal Doppler Weather Radar
TRACON	terminal radar approach control
VMC	visual meteorological conditions

Executive Summary

On December 20, 2008, about 1818 mountain standard time, Continental Airlines flight 1404, a Boeing 737-500, N18611, departed the left side of runway 34R during takeoff from Denver International Airport (DEN), Denver, Colorado. A postcrash fire ensued. The captain and 5 of the 110 passengers were seriously injured; the first officer, 2 cabin crewmembers, and 38 passengers received minor injuries; and 1 cabin crewmember and 67 passengers (3 of whom were lap-held children) were uninjured. The airplane was substantially damaged. The scheduled, domestic passenger flight, operated under the provisions of 14 *Code of Federal Regulations* Part 121, was departing DEN and was destined for George Bush Intercontinental Airport, Houston, Texas. At the time of the accident, visual meteorological conditions prevailed, with strong and gusty winds out of the west. The flight operated on an instrument flight rules flight plan.

The National Transportation Safety Board determines that the probable cause of this accident was the captain's cessation of rudder input, which was needed to maintain directional control of the airplane, about 4 seconds before the excursion, when the airplane encountered a strong and gusty crosswind that exceeded the captain's training and experience.

Contributing to the accident were the following factors: 1) an air traffic control system that did not require or facilitate the dissemination of key, available wind information to the air traffic controllers and pilots; and 2) inadequate crosswind training in the airline industry due to deficient simulator wind gust modeling.

The safety issues discussed in this report include the pilots' actions, training, and experience; air traffic controllers' obtaining and disseminating wind information; runway selection and use; crosswind training; simulator modeling; crosswind guidelines and limitations; certification and inspection of crew seats; and galley latches.

1. Factual Information

1.1 History of the Flight

On December 20, 2008, about 1818 mountain standard time (MST),[1] Continental Airlines flight 1404, a Boeing 737-500, N18611, departed the left side of runway 34R during takeoff from Denver International Airport (DEN), Denver, Colorado. A postcrash fire ensued. The captain and 5 of the 110 passengers were seriously injured; the first officer, 2 cabin crewmembers, and 38 passengers received minor injuries; and 1 cabin crewmember and 67 passengers (3 of whom were lap-held children) were uninjured. The airplane was substantially damaged. The scheduled, domestic passenger flight, operated under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121, was departing DEN and was destined for George Bush Intercontinental Airport (IAH), Houston, Texas. At the time of the accident, visual meteorological conditions (VMC) prevailed, with strong and gusty winds out of the west. The flight operated on an instrument flight rules flight plan.

The pilots arrived at DEN about 1700 (1 hour before the accident flight's scheduled departure). The captain stated that he picked up the flight's dispatch paperwork from Continental's operations coordinator and performed an external preflight inspection while the first officer performed cockpit preflight safety checks. The pilots stated that, after the captain joined the first officer in the cockpit, they performed routine departure preparations, including appropriate checklists and entering load information into the airplane's flight management computer. After these tasks were completed (about 1804, according to the airplane's cockpit voice recorder [CVR])[2], the first officer[3] contacted DEN ramp control[4] for approval to push back from the gate, advising the ramp controller that they had automatic airport terminal information service (ATIS) departure information "Charlie."[5] The DEN ramp controller approved a push back for a west taxi.

The pilots stated that they taxied toward runway 34R[6] without event. About 1812, the DEN air traffic control (ATC) tower (ATCT) ground controller instructed the pilots to monitor the DEN ATCT local controller's frequency while awaiting takeoff clearance. At 1814:27, the DEN ATCT local controller cleared the accident pilots to taxi into position on runway 34R and hold (to ensure adequate separation behind the airplane that took off on runway 34R at 1814:20). The pilots taxied onto the runway and completed the before-takeoff checklist while they held in position on the runway. According to CVR data, at 1816:16, one of the pilots commented, "what

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

[2] The CVR recorded the last 30 minutes and 22 seconds of cockpit communications before the accident. See appendix B for a transcript of the CVR recording.

[3] As the pilot monitoring, the first officer was responsible for radio communications.

[4] The ramp controller coordinates movement of aircraft and vehicles on airport surfaces other than the taxiways and runways.

[5] ATIS continuously broadcasts recorded noncontrol information (for example, information regarding DEN weather conditions) to pilots. DEN broadcasts arrival- and departure-specific ATIS information on different frequencies. ATIS departure information "Charlie" reported winds from 270° at 11 knots. The DEN ATIS data source for weather information is an automated surface observing system station located near the center of the airport.

[6] On the evening of the accident, DEN was using runways 34L, 34R, and 25 for departures.

are the winds?"[7] The accident captain noted to the first officer, "looks like…some wind out there." The first officer replied, "yeah," and the captain stated, "oh yeah, look at those clouds moving."

At 1817:26, the DEN ATCT local controller told the accident pilots that the wind was from 270° at 27 knots, assigned a departure heading of 020°, and cleared them for takeoff on runway 34R.[8] (In their written statements, both pilots noted that although the wind velocity had increased from the 11 knots that had been reported by the ATIS, the tower-reported wind was still within the airline's published crosswind guideline of 33 knots for a clear, dry runway like runway 34R.) The first officer acknowledged the clearance, and, as they began the takeoff roll, the captain stated to the first officer, "alright…left crosswind, twenty ah seven knots…alright look for ninety point nine."[9]

At 1817:49, the CVR began recording the sound of increasing engine noise. The captain stated that, as the airplane accelerated, he shifted the primary focus of his attention from the thrust levers to outside visual references, keeping the airplane on the runway centerline. Meanwhile, according to postaccident interviews, the first officer's attention was primarily focused on monitoring the engine instruments, consistent with company policy. At 1818:04, the first officer advised the captain that the power was set at 90.9 percent. The first officer stated that after the power was set, he shifted his attention to monitoring the airspeed so that he could make the standard airspeed callouts, the first of which was at 100 knots.

During the airplane's initial acceleration along the runway centerline, information from the flight data recorder (FDR) indicated increasing right rudder pedal inputs, while the control wheel and column and their respective control surfaces were at their neutral positions. At 1818:07, as the airplane accelerated through about 55 knots, the airplane's heading began to move left, and the FDR recorded the beginning of a large right rudder pedal input that peaked at 88 percent of its available forward travel[10] about 2 seconds later. This 88-percent right rudder pedal input was followed by a substantial reduction, reaching about 15 percent by 1818:09.75. Almost simultaneous with the onset of this large rudder pedal input, the FDR began to record a left control-wheel input. The nose of the airplane moved to the right; however, at 1818:10, as the airplane was accelerating through about 85 knots, the airplane's nose reversed direction and began moving back to the left at a rate of about 1° per second. This leftward movement of the nose continued for about 2 seconds and was accompanied throughout its duration by another substantial right rudder pedal input. This second large right rudder pedal input peaked at 72 percent of available forward displacement at 1818:11.75 and a speed of more than 90 knots and then decreased again, reaching 33 percent at 1818:13.25.[11]

[7] This comment was recorded only by the cockpit area microphone (CAM), not by either pilot's headset microphone, and it was not possible to identify which pilot made the comment.

[8] A wind from 270° at 27 knots would result in a crosswind component of 26.6 knots for an airplane taking off on DEN's runway 34R, which has a magnetic heading of 350°.

[9] The "ninety point nine" referenced by the captain was the calculated takeoff thrust as a percentage of the engines' N_1 (low pressure spool) speed.

[10] For the purposes of this report, percentage of available forward travel is defined as the forward displacement of the right rudder pedal in degrees divided by the number of degrees between the rudder pedal's neutral position and its maximum forward displacement.

[11] Postaccident examination of the runway revealed visible tire skid marks on the pavement corresponding to the airplane's veering to the left from the runway centerline to the edge of the runway.

During this second large right rudder pedal movement (at 1818:12), the airplane's left turning motion slowed for about 1 second, and then the nose began moving rapidly to the left again. A fraction of a second later (at 1818:13.25), the right rudder pedal was abruptly relaxed (reaching its neutral position about 1 second later). At 1818:13.5, the CVR recorded one of the pilots exclaiming, "Jesus,"[12] and, at 1818:13.6, the FDR recorded the beginning of a transition from left control wheel input (consistent with crosswind takeoff technique for a left crosswind) to right control wheel input (crossing the control wheel's neutral point at 1818:14). Although the pilot briefly made a small right rudder pedal input at 1818:14.25, the FDR did not record any more substantial right rudder pedal inputs as the airplane continued to veer to the left. Figure 1 on the following page shows graphs of the estimated wind speeds and the airplane's FDR-recorded heading, rudder pedal position, and lateral acceleration during the takeoff roll. (For additional information on the estimated wind speeds, see section 1.16.)

At 1818:15, the CVR recorded the first officer saying, "oh [expletive]." At 1818:17, the CVR began to record the sound of increasing background noise as the airplane left the runway, and, at 1818:21, the captain called to reject the attempted takeoff. FDR data showed engine power reductions, as well as activation of the brakes. Thrust reverser deployment began about 3 seconds after the airplane left the runway.

The investigation revealed that the airplane departed the left side of runway 34R about 2,600 feet from the approach end and crossed taxiway WC and an airport service road before coming to a stop on a heading of about 315° in an area just north of DEN aircraft rescue and firefighting (ARFF) fire station #4. (See figure 2 on page 5.) The airplane was still moving at a speed of about 90 knots when electrical power was lost, and the FDR and CVR stopped recording at 1818:27. Postaccident interviews with passengers and crewmembers, as well as evidence from the crash site, indicated that, as the airplane crossed the uneven terrain before coming to a stop, it became airborne, resulting in a jarring impact when it regained contact with the ground.

According to the captain, after the airplane left the runway and he subsequently initiated the rejected takeoff, they were "along for the ride." Both pilots stated that there were a couple of "very painful" bumps before the airplane came to a stop. They indicated that they were somewhat dazed or "knocked out" for 1 or 2 minutes after the airplane stopped and made no immediate attempts to get up or leave the cockpit. The first officer stated that he could hear activity from the cabin and considered making an announcement, but he was hindered because the cockpit was completely dark. By the time the pilots left the cockpit, the cabin crew, assisted by some deadheading pilots, had evacuated all of the passengers. The first officer and a deadheading captain were the last to exit the airplane.[13]

[12] As with the earlier wind-related comment, this exclamation was recorded only by the CAM, and it was not possible to identify which pilot made the comment.

[13] After the airplane came to a stop, a fire developed on the airplane's right side; however, all occupants were successfully evacuated before the fire breached the cabin. For additional information, see sections 1.14 and 1.15.

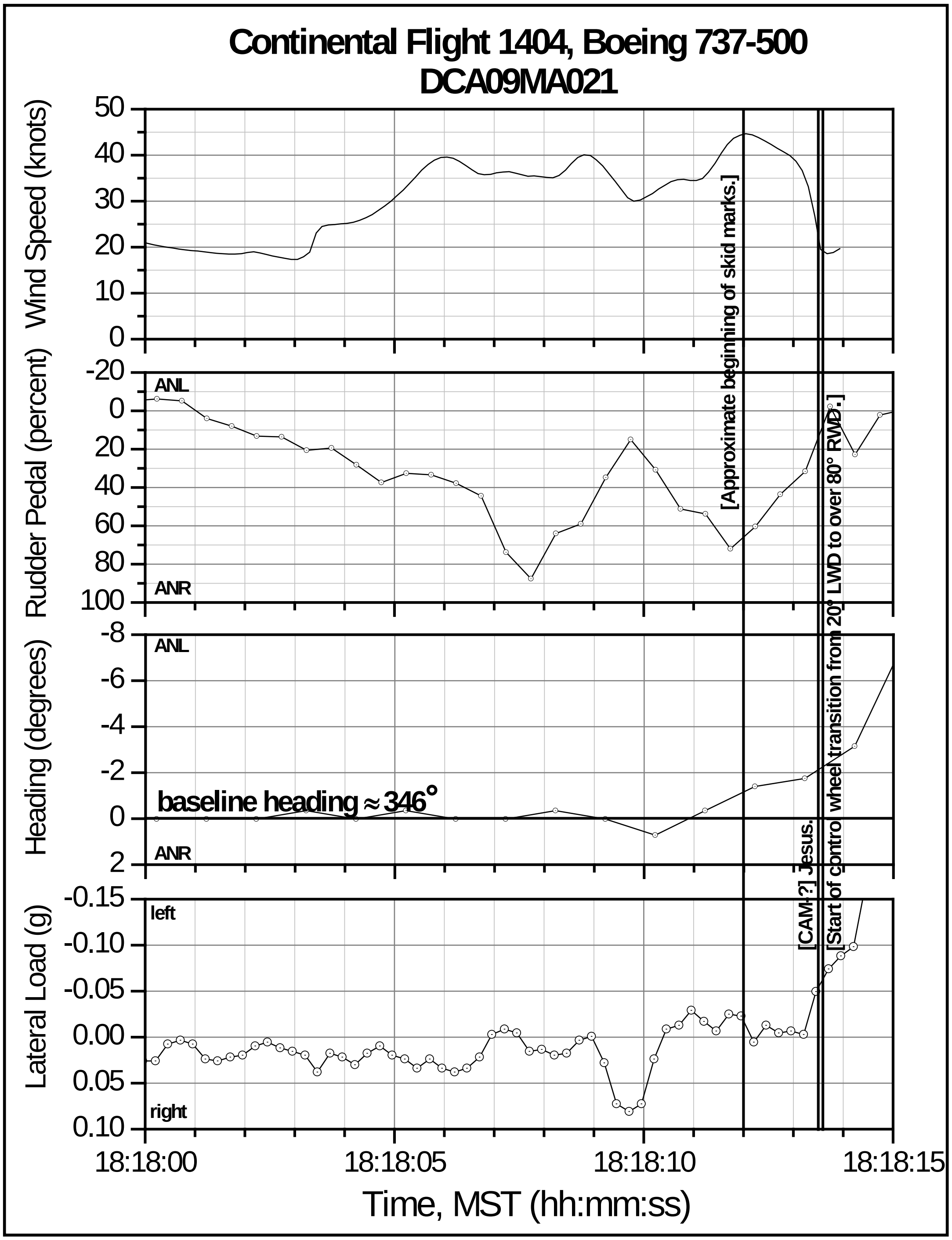

Figure 1. Graphs showing the estimated wind speeds and the airplane's FDR-recorded heading, rudder pedal position, and lateral acceleration during the takeoff roll. The timing of the beginning of the skid marks, the "Jesus" comment, and the control wheel reversal are also shown.

Figure 2. Aerial photograph (facing southeast) of the airplane wreckage. Ground scars are visible from the edge of runway 34R, across taxiway WC and the airport service road, and up to the wreckage. Fire station #4 is shown at the right edge of the photograph.

During postaccident interviews, the captain told investigators that the takeoff roll initially felt normal; he described it as "relatively smooth, with no shimmying or shaking of the aircraft." The captain reported that, as the airplane accelerated through about 90 knots, he "felt the rear end of the airplane slip out hard to the right and the wheels lose traction. It felt like a slick patch of runway or a strong gust of wind or a combination of both…." The captain further described the sensation, stating that it felt like "someone put their hand on the tail of the airplane and weathervaned it to the left." The captain stated that he tried to counter the airplane's movements with full right rudder pedal inputs, but the airplane continued to "track hard toward the left runway lights." He indicated that, as the airplane neared the edge of the runway, he tried to use the tiller to steer the airplane back to the right, without success.

The first officer stated that he was monitoring the airplane's power settings and acceleration and was anticipating the 100-knot callout. He stated that, around 90 knots, he glanced outside and noted "a slight deviation left of centerline, but we seemed to be correcting back to the right." However, the airplane then "abruptly swung approximately 30[°] left with the tail to the right and we were heading for the left side of the runway."

1.2 Injuries to Persons

Table 1. Injury chart.

Injuries	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	0	0	0	0	0
Serious	1	0	5	0	6
Minor	1	2	38	0	41
None	0	1	67	0	68
Total	2	3	110	0	115

1.3 Damage to Airplane

The airplane was substantially damaged, and a postcrash fire occurred.

1.4 Other Damage

A taxiway light fixture and several green reflector poles along the airport service road were damaged.

1.5 Personnel Information

1.5.1 The Captain

The captain, age 50, was hired by Continental on November 5, 1997. He served as first officer on the company's DC-9, Boeing 737 (737), and Boeing 757/767 airplanes before he transitioned to the 737 captain position about 14 months before the accident. He held a multiengine airline transport pilot (ATP) certificate with type ratings in the 737/757/767 model airplanes. He had completed his most recent line check on April 14, 2008, and completed his most recent recurrent training and proficiency checks on October 9 and 11, 2008, respectively. (Records also showed that the captain had successfully completed the Continental Airlines 737 2004/2005 Continuing Qualification Syllabus, which included at least one takeoff and one landing in a 35-knot direct crosswind.) The captain held a first-class Federal Aviation Administration (FAA) airman medical certificate, dated September 16, 2008, with no restrictions or limitations.

The captain began his aviation career when he joined the U.S. Navy in 1979, and he had about 4,500 hours of flight experience when he left active duty in 1993.[14] At the time of the accident, the captain had flown about 13,100 total hours, including about 6,300 hours in the 737.[15] Records show that the captain had flown about 915, 81, and 4 hours in the 12 months,

[14] According to his military records, the captain had flown in combat, completed several hundred aircraft carrier landings, and been awarded numerous air medals.

[15] The captain's flight experience was estimated based on company records and information provided by the captain.

30 days, and 24 hours, respectively, before the accident. (For additional information, see section 1.5.3.)

The National Transportation Safety Board (NTSB) conducted postaccident interviews with several Continental pilots who had flown with or provided training/line checks to the accident captain regarding the captain's flying skills. The accident first officer had flown with the captain previously and enjoyed working with him. The first officer complimented the captain's crew resource management, threat and error management, and technical and communication skills. When asked to rate the captain's flying skills on a scale of 1 to 10 compared to other pilots with whom he had flown, the first officer rated the captain as a 9 and stated that he was very competent. Two other first officers who had flown with the captain indicated that his performance was typical of a Continental captain, one saying that he was "by the book" and that it was good to fly with him. A line check airman stated that the line check he flew with the captain about 8 months before the accident "was a normal flight."

A review of Continental's records for the accident captain revealed no evidence of training or performance deficiencies. A search of the captain's FAA records revealed no FAA enforcement actions, incidents, or previous accidents and no history of failures or retests for FAA airman certificates and/or ratings. A search of the National Driver Register found no record of driver's license suspension or revocation.

1.5.2 The First Officer

The first officer, age 34, was hired by Continental as a 737 first officer in March 2007. The first officer held a multiengine ATP certificate with type ratings in the DeHavilland DHC-8 and 737. He had completed his most recent line check on September 29, 2008, and completed his most recent recurrent training and proficiency checks on December 1 and 2, 2008, respectively. He held a first-class FAA airman medical certificate, dated March 12, 2008, with no restrictions or limitations.

The first officer began his aviation career at the University of North Dakota in 1994. After graduating in May 1998, he remained at the university as a flight instructor for about 1 year. In June 1999, the first officer was hired by Horizon Air as a first officer in DHC-8 airplanes. At the time of the accident, the first officer had flown about 8,000 total hours, including about 1,500 hours in the 737.[16] Records show that the first officer had flown about 918, 34, and 4 hours in the 12 months, 30 days, and 24 hours, respectively, before the accident. (For additional information, see section 1.5.3.)

The NTSB conducted postaccident interviews with several Continental pilots who had flown with or provided training or line checks to the accident first officer regarding the first officer's flying skills. The accident captain had flown with the first officer before and got along with him well. The captain rated the first officer's proficiency in the top 10 percent of the company's pilots and added that he communicated well. One flight instructor and simulator check airman recalled having a favorable impression of the first officer during a recent check. A captain who had flown with the first officer about 2 months before the accident indicated that the first officer had been professional, alert, responsive, and attentive. That captain rated the first

[16] The first officer's flight experience was estimated based on company records and information provided by the first officer.

officer's proficiency as "above average in many ways." Another captain who had flown with the first officer ranked his proficiency as "in the top 5 percent" of Continental first officers and noted that the first officer was a "pleasant guy to work with."

A review of Continental's records for the first officer revealed no evidence of training or performance deficiencies. A search of the first officer's FAA records revealed no FAA enforcement actions, incidents, or previous accidents and no history of failures or retests for FAA airman certificates and/or ratings. A search of the National Driver Register found no record of driver's license suspension or revocation.

1.5.3 Pilots' Recent History

The accident occurred on the fourth day of a 4-day pairing for the captain and first officer. (The pilots had been paired with each other previously, most recently about a month before the accident.) Company records show that on December 17 (the first day of the latest pairing), the captain and the first officer operated a flight from IAH[17] to San Francisco International Airport (SFO), San Francisco, California. They were on duty from about 0630 central standard time to about 1022 Pacific standard time (PST), a duty period of 5 hours and 52 minutes, which included 4 hours and 28 minutes of flight time. On December 18, the pilots flew from SFO to IAH and then from IAH to Philadelphia International Airport (PHL), Philadelphia, Pennsylvania. They were on duty from about 1017 PST to 2147 eastern standard time (EST), a duty period of 8 hours and 30 minutes, which included 6 hours and 34 minutes of flight time. On December 19, the pilots flew from PHL to IAH and then from IAH to DEN. They were on duty from about 1500 EST to about 2154 MST, a duty period of 8 hours and 54 minutes, which included 6 hours and 19 minutes of flight time. On December 20, the pilots reported for duty about 1700 (1 hour before the accident flight's scheduled departure).

The captain's activities in the days before the accident were reconstructed based on company records and postaccident interviews with the captain and others. The captain had been on vacation for 9 days before this 4-day pairing except for a "red-eye" flight he picked up about a week before the accident. He described routine activities during nonwork periods and stated that he felt good and well-rested during the 4-day pairing.[18] The captain told investigators that he felt "upbeat" and rested on the day of the accident. During postaccident interviews, the first officer confirmed that the captain was in a good mood and appeared rested, a Continental operations coordinator reported that the captain seemed "normal," and the Continental gate agent who helped board the flight's passengers stated that the captain seemed alert and friendly.

The first officer's activities in the days before the accident were also reconstructed based on company records and postaccident interviews with the first officer and others. The first officer had not flown a trip for about 2 weeks before this 4-day pairing, which began on December 17. He described routine activities during nonwork periods and stated that, although he had a mild sore throat and his sleep was "not great" early in this crew pairing, he felt better and more rested by the third day. The first officer told investigators that his throat felt a little scratchy before the

[17] Both pilots resided near Houston, Texas.

[18] The captain stated that he needed 8 hours of sleep per night to feel rested, and he reported spending 8.5 or more hours in bed per night for the 3 nights preceding the accident.

accident flight but that he did not feel ill or think that his ability to perform was diminished.[19] The captain told investigators that the first officer seemed "upbeat" on the day of the accident, and the Continental gate agent who boarded the flight's passengers did not notice anything unusual about the first officer.

1.6 Airplane Information

1.6.1 General

The accident airplane, serial number 27324, was manufactured by Boeing in June 1994. According to Continental records, at the time of the accident, the airplane had accumulated about 40,541 total flight hours and 21,511 total cycles.[20] The airplane was equipped with two CFM56-3B1 wing-mounted turbofan engines.[21] The left engine had been operated about 39,092 hours total time, and the right engine had been operated about 28,081 hours total time; the left and right engines had been operated about 800 and 5,296 hours since inspection, respectively.

In November 2008, the airplane was modified by the installation of winglets.[22] Company records showed that the modification work was performed in accordance with Continental Airlines Engineering Authorization 5730-02222, revision F, and was approved per an FAA form 337, "Major Repair and Alteration (Airframe, Powerplant, Propeller, or Appliance)," dated December 6, 2008.

According to company documents and postaccident calculations, the airplane's takeoff weight for the accident flight was about 116,900 pounds, and the calculated center of gravity (cg) was 21.5 percent mean aerodynamic chord (MAC); both parameters were within the required limits.[23]

1.6.2 737 Ground Directional Control Systems

During ground maneuvers and taxiing, the nosewheel steering system provides directional control of the airplane. This system can be controlled with a steering tiller, located on the left side of the cockpit (accessible only by the captain) and/or by the rudder pedals at either pilot position. According to Boeing and Continental 737 operating manuals, the nosewheel steering tiller is used to turn the nosewheel assembly through the full range of travel at low taxi speeds (about 20 knots, according to Continental's manual). Boeing and Continental airplane flight manuals specify that maximum nosewheel steering effectiveness is available with rudder pedal steering when above normal taxi speeds, and that, during the takeoff roll, the airplane

[19] The first officer stated that he needed 7 to 9 hours of sleep per night to feel rested, and he reported spending 8 or more hours in bed per night for the 3 nights preceding the accident.

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

[21] The CFM56-3B1 is manufactured by partner companies General Electric in the United States and SNECMA (Societe Nationale d'Etude et de Construction de Moteurs d'Aviation) Moteurs of France.

[22] According to Continental personnel, winglets reduce fuel consumption by up to 5 percent. The company was installing winglets on all its non-winglet-equipped 737 airplanes.

[23] According to the 737 airplane flight manual, the airplane's maximum gross takeoff weight was 138,500 pounds, and the allowable takeoff cg range was between 5 and 25 percent MAC.

should be kept on the runway centerline through the use of rudder pedal steering and inputs to the rudder surface. (Steering inputs through the tiller can result in up to 78° of nosewheel deflection, whereas rudder pedal steering inputs can only command about 7° of nosewheel deflection.) According to Boeing, as the airplane accelerates to between 40 and 60 knots during the takeoff roll, the rudder surface becomes effective and is used increasingly for directional control. In response to a pilot's rudder pedal inputs, the rudder surface can be moved left or right to deflections of up to 26°.

1.7 Meteorological Information

1.7.1 General

About the time of the accident, National Weather Service (NWS) surface analysis charts showed a low-pressure system near the Colorado/New Mexico border, with a stationary front extending north-south through those states, passing immediately east of DEN. A high-pressure ridge extended through Nevada and Utah into western Colorado. The resultant pressure pattern across the Denver area resulted in westerly winds across the Rocky Mountains. Review of the NWS surface analysis charts, upper air data, and satellite imagery for the area also indicated that conditions might have been favorable for the formation of downslope winds with moderately strong wind gusts and mountain wave activity. (For additional information on mountain waves, see section 1.7.3.)

The NWS Terminal Aerodrome Forecast issued for DEN about 1638 predicted the following conditions between 1700 and 1900 on the day of the accident:

> Wind from 300° at 16 knots with gusts to 24 knots, visibility greater than 6 statute miles, a few clouds at 4,000 feet above ground level [agl] and scattered clouds at 12,000 and 22,000 feet.

The official weather observations at DEN are made by an automated surface observing system (ASOS), the sensors for which are located east of the main passenger terminal, near the middle of the airfield (about 2.4 miles southeast of the accident site)[24] at a height of 33 feet agl.[25] The ASOS system is augmented and backed up by NWS-certificated weather observers 24 hours a day, 7 days a week. The sensor samples wind direction and speed every second, and the system computes and records various running averages (for instance, 3-second peak, 5-second average, and 2-minute average wind). The 2-minute average wind direction and speed is the wind value that is recorded and disseminated in Meteorological Aerodrome Reports (surface weather observations) and in ATIS reports.[26] The official weather observations around the time of the accident were as follows:

[24] The DEN ASOS sensor is located near low-level windshear alert system sensor #14 .

[25] The DEN ASOS wind sensor height was consistent with Federal standards established in an effort to standardize automated weather observing installations at U.S. airports and heliports and with the international standards established by the World Meteorological Organization and International Civil Aviation Organization. These standards specify that ASOS wind sensors be installed at a height of 10 meters, or about 33 feet, above the ground.

[26] The ASOS uses the 3-second peak wind values, which are stored for up to 10 minutes, to determine wind gusts. If the 2-minute average wind is equal to or greater than 9 knots and the largest 3-second peak wind speed during the last minute exceeds the current 2-minute average wind by 5 knots or more, a gust is reported.

> DEN weather at 1753: wind from 280° at 11 knots, visibility unrestricted at 10 miles, a few clouds at 4,000 feet agl, scattered clouds at 10,000 feet, temperature minus 6° C, dew point temperature minus 16° C, altimeter setting 29.97 inches of Mercury (Hg). Remarks: peak wind from 290° at 27 knots at 1700.
>
> DEN special weather observation at 1834: wind from 290° at 24 knots, gusts to 32 knots, visibility 10 miles, a few clouds at 4,000 feet agl, scattered clouds at 10,000 feet, temperature minus 4° C, dew point temperature minus 18° C, altimeter setting 29.98 inches of Hg. Remarks: peak wind from 280° at 36 knots at 1823.

A review of the ASOS 5-minute weather observations[27] around the time of the accident showed that 11-knot winds were reported at 1815:31, and, 5 minutes later (at 1820:31), the winds were 24 knots with gusts to 32 knots. A review of the ASOS 1-minute wind data indicated that, at the time the airplane departed the runway, the wind was from 282° at 18 knots with gusts to 23 knots. The maximum ASOS 1-minute wind (277° at 36 knots) was recorded about 1823.

1.7.2 Low-Level Windshear Alert System and Wind Speeds

To detect low-level windshear conditions around airports, the FAA installed basic low-level windshear alert systems (LLWAS), consisting of a centerfield sensor and five additional sensors located around the airport's periphery at 110 U.S. airports with ATCTs. Since the initial installations, the FAA has improved LLWAS systems, upgrading software and hardware, integrating the system with an airport's Terminal Doppler Weather Radar (TDWR) and Integrated Terminal Weather System (ITWS), and adding sensors along runway approach and departure corridors.

DEN is equipped with the LLWAS network expansion rehost system (LLWAS-NE^{++}), the most advanced LLWAS system. The system is designed to continuously collect and analyze wind data collected by 32 remote sensor stations located on and around the airport. Figure 3 is a diagram of the DEN airport with LLWAS sensor locations shown.

[27] The ASOS 5-minute weather observations are displayed in the ATCT cab and the weather observer's station, but they are not disseminated.

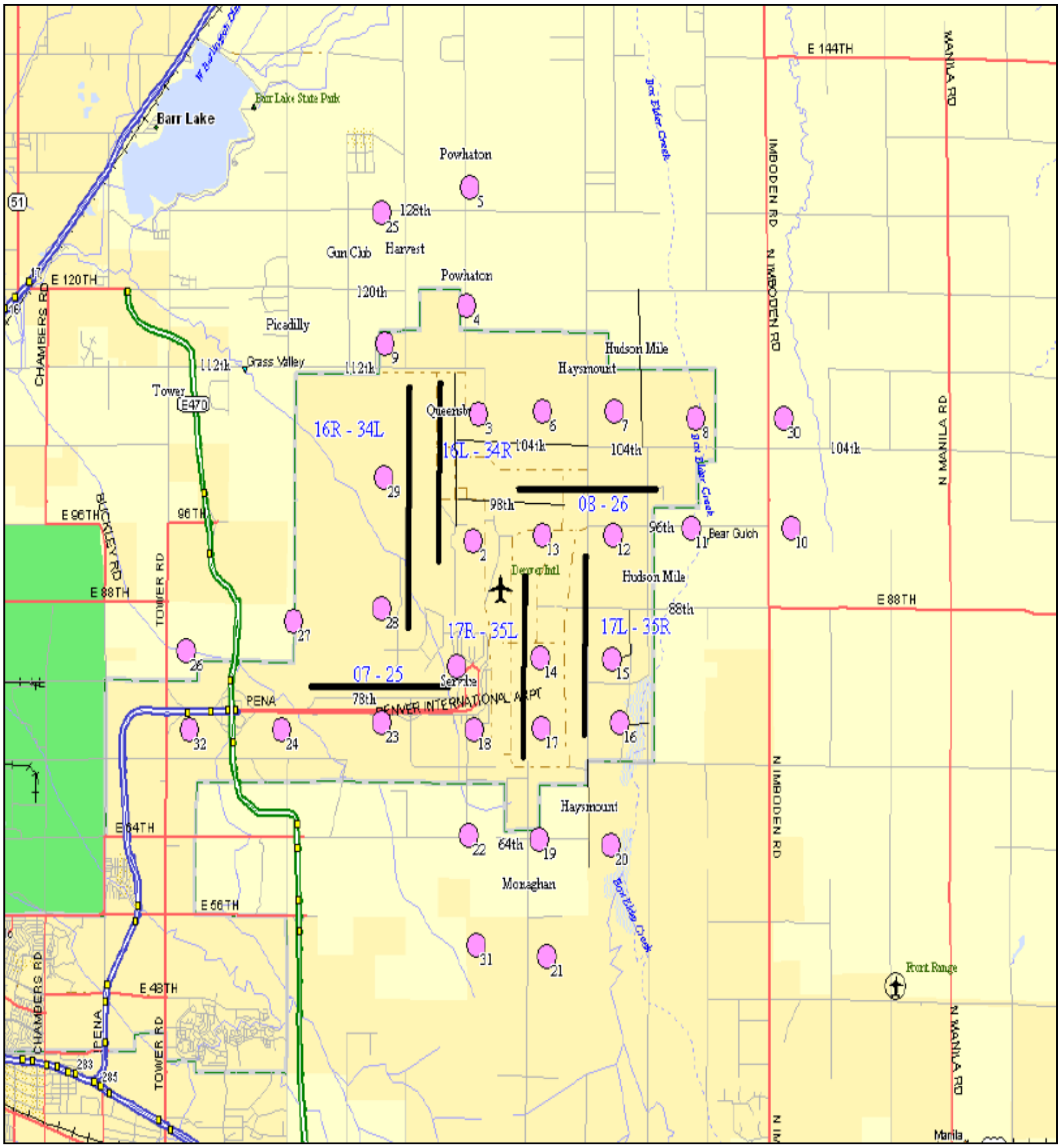

Figure 3. Diagram of the DEN airport, with LLWAS sensor locations shown.

The sensors report wind information at 10-second intervals and are positioned to provide wind speed and direction for all runway surfaces. The LLWAS system continuously evaluates wind speed and direction reports to determine whether windshear and/or microburst conditions exist. DEN's ITWS continuously gathers information from the LLWAS-NE^{++} system, ASOS, and other airport weather data sources and integrates and displays the information for use by DEN ATC personnel.[28] If windshear and/or microburst conditions do exist, related alerts are displayed to air traffic controllers on the ribbon display terminals (RBDT) in the tower. ITWS also provides wind information from LLWAS sensors to the DEN ATCT RBDTs.

[28] Other weather data sources integrated by DEN's ITWS include the airport's TDWR and NEXRAD systems, as well as two local airport surveillance radar (ASR-9) facilities.

The LLWAS wind data from sensor #2 (located near the approach end of runway 34R at 110 feet agl), #3 (located near the departure end and east of runway 34R at 100 feet agl), and #29 (located near the middle and west of runway 34R at 40 feet agl) provided representative wind conditions for runway 34R during this time. (LLWAS sensor #2 was the only DEN wind sensor that reported wind gusts.) Figure 4 is a plot showing the reported winds from LLWAS sensors #2, #3, and #29 relative to runway 34R at 1818:12.

As shown in figure 4, the maximum wind speed recorded by DEN LLWAS sensors at the time of the accident was 34 knots, recorded by sensor #2, which is located closest to the approach end of runway 34R. The maximum LLWAS-reported wind around that time (40 knots) was also recorded by sensor #2, about 2 minutes before the accident.[29] (See the bold text in table 2.) With further processing (such as averaging wind values and factoring in winds recorded

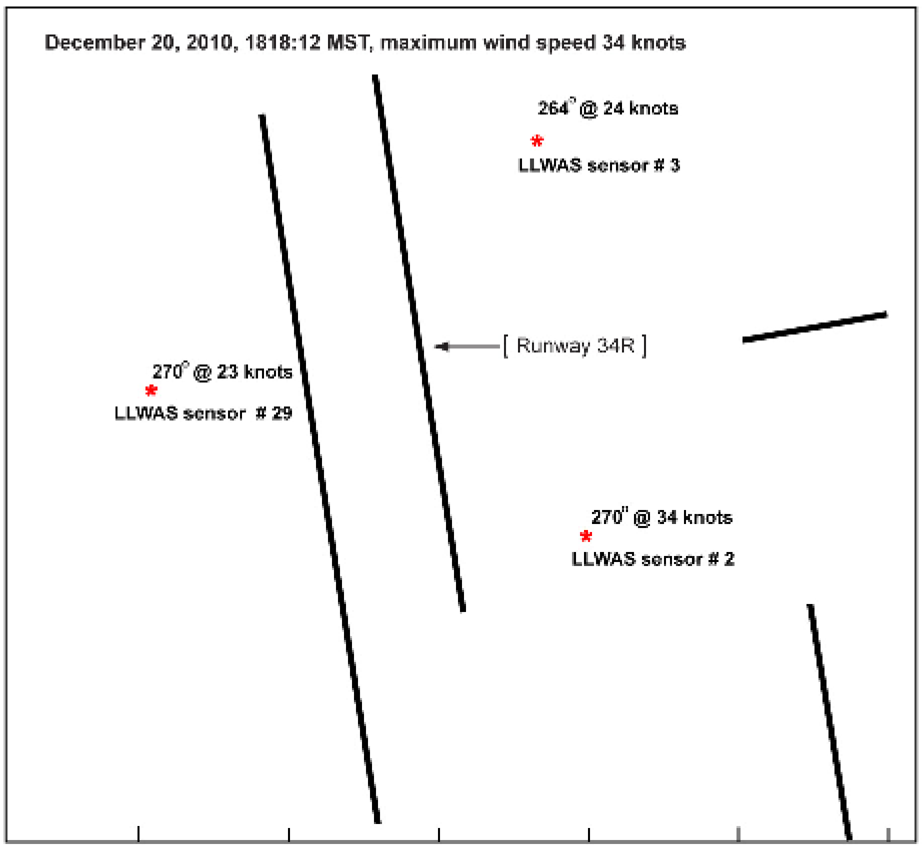

Figure 4. This plot shows the reported winds from LLWAS sensors #2, #3, and #29 at 1818:12.

[29] LLWAS sensor #14, which is located near DEN's ASOS sensor near the center of the airport, reported similar wind speeds during the period.

by other sensors for gust information), wind information recorded by LLWAS sensor #2 is displayed as the airport wind (AW) on the DEN ATCT RBDTs.[30]

Table 2. Wind direction (in degrees) and speed (in knots) recorded at 10-second intervals by LLWAS sensors #2 and #3.

Time	Sensor #2	Sensor #3
1816:02	280° @ 30	266° @ 24
1816:12	286° @ 36	268° @ 25
1816:22	**282° @ 40**	268° @ 23
1816:32	280° @ 38	269° @ 25
1816:42	278° @ 38	268° @ 26
1816:52	278° @ 35	267° @ 28
1817:02	273° @ 32	265° @ 27
1817:12	276° @ 35	268° @ 26
1817:22	270° @ 33	270° @ 25
1817:26	272° @ 34	268° @ 27

Note: The maximum LLWAS-reported wind is shown in bold text.

At the NTSB's request, the National Center for Atmospheric Research (NCAR) conducted an in-depth review of the wind data reported by DEN LLWAS sensors around the time of the accident. NCAR produced an animation showing the LLWAS-recorded winds between about 1813 and 1823, which indicated that the winds across the airport were not uniform; the animation showed a band of strong westerly winds over the central portion of the airport, with lighter winds to the north and south. In their review of the accident-related wind data, NCAR personnel emphasized that, because the LLWAS wind samplings do not record wind gusts that may occur during the 10-second intervals between recorded samples, it is likely that peak wind gusts were stronger than the winds that were depicted.

1.7.3 Mountain Wave Conditions

According to FAA Advisory Circular (AC) 00-57, "Hazardous Mountain Winds and their Visual Indicators," mountain wave activity can occur in high terrain with wind speeds increasing with rising terrain, reaching at least 20 knots at peak elevations, and with little variation in the wind direction flowing across the mountain ridge. A stable layer is often found above the mountains. Under these conditions, the airflow over the mountain ridge produces a harmonic oscillation, an atmospheric wave of rising and sinking motions that might extend hundreds of miles downstream from the mountains (a mountain wave). Under extreme conditions, these elements can result in turbulence,[31] strong downslope winds, an atmospheric pressure jump, and rotor clouds. According to AC 00-57, the mountain-wave-related concerns for takeoffs and/or

[30] The AW is the 2-minute average wind value recorded by LLWAS sensor #2 and is updated every 10 seconds. When an AW gust value is displayed, it is based on the highest 1-second wind from any of the 32 sensors that is 3 knots higher than sensor #2's 2-minute average wind value and is maintained for 10 minutes.

[31] Numerous pilot reports (PIREPs) of turbulent conditions over Colorado associated with mountain wave activity were recorded between about 1500 and 2300 the night of the accident. The highest incidents of turbulence occurred between 17,000 and 19,000 feet. Several pilots reported airspeed variations of +/- 15 knots and 500 feet altitude deviations. There were two PIREPs citing encounters with severe to extreme turbulence, which by definition indicates that the airplane was impossible to control and might have incurred structural damage. In addition, there were several PIREPs of low-level windshear during the period.

landings include a loss of directional control on or near the runway. The AC indicates that localized surface wind gusts in excess of 50 knots are not unusual.

Much of the research on mountain waves in Colorado has focused on severe windstorm events that have resulted in damage to surface structures in the Boulder, Colorado, area. However, mountain wave wind events resulting in intermittent strong surface winds and gustiness further east near Denver have not been well studied. Therefore, there is little information regarding the magnitude and frequency of mountain-wave-related wind events or periods of moderate gustiness at DEN.

To assess whether mountain waves could have played a role in the gusty surface wind conditions at DEN at the time of the accident, NCAR simulated conditions around that time using a high-resolution numerical model.

The results of this model indicated that significant mountain wave activity existed in the area at the time. The model showed a well-defined wave over the mountains with a wave trough extending downward above the foothills to the west of DEN. NCAR's numerical model showed that the position of this wave trough did not change much during the hour surrounding the accident and indicated that the amplitude of the wave increased significantly shortly before the accident. NCAR's model showed an area with winds of 80 knots to 100 knots in the higher elevation foothills west of the airport and winds of 40 knots to 68 knots at the airport between about 1808 and 1818.

The NCAR model showed that the undulating motion of these waves as they moved eastward across DEN resulted in strong, very localized, intermittent gusts at the airport's surface. NCAR's images depicted generally stronger westerly flow to the north of the airport, with large regions of relatively lighter winds over the center and southern portions of the airport. There were areas to the south of the airport where the flow was easterly. Embedded in the overall flow structure were many gusts, which move from west to east across the airport area. NCAR's model indicated a particularly strong wind gust (speeds exceeding 68 knots) moving across the southern end of the airport between about 1808 and 1818. Another strong wind gust (speeds as high as 45 knots) was also indicated; this gust moved across the center of the airport, directly crossing the accident site, between about 1814 and 1816. At this time (1816:47), the accident CVR recorded the captain saying, "looks like…some wind out there" and, 10 seconds later, "oh yeah look at those clouds moving."[32]

1.8 Aids to Navigation

No problems with any navigational aids were reported.

1.9 Communications

No technical communications problems were reported.

[32] In addition, investigators received a report of a wind gust of an estimated 50 mph that lasted 2 to 3 minutes from a couple driving a vehicle west of the airport. Further, an airline captain in an airplane parked at one of the DEN gates closest to the accident site told investigators that he heard a rumbling sound and felt the airplane buffet as a result of a sudden increase in wind near the time of the accident. This captain saw debris blowing on the ramp and ramp personnel having trouble standing in the high winds. He estimated the wind gust speed exceeded 50 mph and lasted 45 to 50 seconds.

1.10 Airport Information

DEN is located about 16 miles northeast of Denver, Colorado, at an elevation of about 5,431 feet mean sea level. The airport is served by the following six runways: 16L-34R, 16R-34L, 17L-35R, 17R-35L, 7-25, and 8-26. Other than runway 16R-34L, which is 16,000 feet long by 200 feet wide, all DEN runways (including runway 34R, the active runway for the accident flight) are 12,000 feet long by 150 feet wide with grooved concrete surfaces.

According to DEN records, the last snow removal operations conducted before the accident followed a snow event on December 18, 2008. An airfield inspection conducted about 8 hours before the accident described the runway surface as bare and dry.[33] An inspection of runway 34R conducted about 1821 (about 3 minutes after the accident) confirmed that the runway surface was bare and dry. A runway friction test of runway 34R conducted about 1821 indicated a normal/good surface condition.

1.10.1 Airport Layout Plan Narrative Report Information

According to the DEN airport layout plan (ALP) narrative report (dated October 7, 2004), when DEN opened in February 1995 (replacing Denver's Stapleton Airport), it had five 12,000-foot long runways: three in a generally north/south orientation and two in a generally east/west orientation. The DEN ALP narrative report included designs/plans for ongoing expansion to accommodate the anticipated growth of the Denver metropolitan area, including the eventual construction of seven additional runways: five in a generally north/south orientation and two in a generally east/west orientation. At the time of the accident, one of the planned additional north-south runways—the 16,000-foot long runway 34L/16R—listed in the ALP narrative report had been constructed.

The ALP narrative report stated that during VMC,[34] arriving traffic normally uses three runways (two north-south runways and one east-west runway), and departing traffic uses three other runways (again, two north-south runways and one east-west runway). The airport can also be operated with three of the north-south runways for arrivals and one north-south runway and both east-west runways for departures. If winds permit, the use of the east-west runways to supplement the north-south runway configuration is based on the airplane's route of flight; for example, westbound arrivals and departures use runway 25 or 26, whereas eastbound arrivals and departures use runway 7 or 8. According to the ALP narrative report, these configurations in VMC allow an estimated capacity of 110 to 120 arrivals per hour and 120 to 130 departures per hour.[35]

1.10.2 Airport Noise Abatement

The DEN airport noise abatement program (Denver Municipal Airport System Rules and Regulations, Part 210 – Noise Abatement and Runway Procedures, effective March 9, 1994)

[33] Two notices to airmen that were in effect at the time of the accident reported patches of snow, ice, and/or slush on taxiways and ramp surfaces.

[34] According to the ALP, DEN experiences VMC about 94 percent of the year.

[35] An operation at DEN ATCT is a landing, a takeoff, or an ATC-monitored overflight of the airport. DEN ATCT estimated 650,000 operations in calendar year 2008.

addresses preferential runway procedures for noise abatement practices for noise-critical aircraft. The 737-500 is not categorized as a noise-critical aircraft in this program.

1.10.3 Runway Selection and Use

According to the DEN ATCT standard operating procedures (SOP) 7110.11B, Paragraph 3-7-3, the DEN ATCT operational-supervisor-in-charge (or controller-in-charge [CIC]) is responsible for determining the runway configuration and appropriately coordinating with all ATC positions. DEN air traffic personnel stated that ATCT and terminal radar approach control (TRACON) personnel work together when selecting the optimal runway configuration, taking into consideration factors such as the prevailing and forecast winds, winds aloft, runway availability, airport activity and traffic flow, snow removal efforts, and density altitude.

Because of DEN's location and level of traffic, its operations have a significant effect on the entire National Airspace System (NAS). Therefore, DEN ATC management personnel also participate in national- and regional-level operational planning teleconferences, which include the FAA Command Center, Air Route Traffic Control Centers, major FAA approach control facilities, and air carriers operating in the NAS. The possible effect of a major airport's runway configuration and arrival rate on the NAS is discussed during these teleconferences.

Official guidance addressing ATC runway selection and use is contained in FAA Order 7110.65, "Air Traffic Control," Chapter 3, Paragraph 3-5-1, which states the following:

> Except where a "runway use" program is in effect, use the runway most nearly aligned with the wind when 5 knots or more or the "calm wind" runway when less than 5 knots…unless use of another runway:
>
> 1. will be operationally advantageous, or
>
> 2. is requested by the pilot.
>
> NOTE:
>
> *1. If a pilot prefers to use a runway different from that specified, the pilot is expected to advise ATC.*
>
> *2. At airports where a "runway use" program is established, ATC will assign runways deemed to have the least noise impact. If in the interest of safety a runway different from that specified is preferred, the pilot is expected to advise ATC accordingly. ATC will honor such requests and advise pilots when the requested runway is noise sensitive.*

The FAA describes a runway-use program as a runway-selection plan designed to enhance noise abatement efforts with regard to airport communities for arriving and departing aircraft. At the time of the accident, DEN ATCT did not, and was not required to, have a formal runway-use program.

The DEN ATCT and TRACON managers described DEN ATC's unofficial policy for determining runway configuration as follows:

- Use the runway configuration that provides the greatest operational advantage (airport acceptance rate) until the crosswind velocity reaches about 20 knots.
- At crosswinds between 25 and 30 knots, consider using the runway utilization most nearly aligned with the wind.
- At crosswinds of 30 knots or greater or if a pilot requests a different runway/refuses to use the existing configuration, consider using a different runway configuration.[36]

According to DEN ATC management personnel, arriving aircraft were the primary consideration in selecting the airport runway configuration, and, when circumstances dictated the use of runways other than the north/south runways, the airport capacity could be adversely affected and pilots could encounter longer taxi routes. (A review of DEN's runway use statistics from fiscal years 2005 to 2008 showed that east/west-only runway configurations were used for 130 hours out of 35,064 total airport hours.)

At the time of the accident, of the nine possible runway configurations available to DEN ATC, the "Landing North/West" configuration was in use. In this configuration, traffic was landing on runways 35L, 35R, 34R, and 26, and traffic was departing on runways 34L, 34R, and 25. The DEN ATCT local controller, who was responsible for departing traffic on all three departure runways, cleared seven airplanes for takeoff[37] in about 9 minutes before the accident occurred. (Two more airplanes were holding in position on runways awaiting takeoff clearance when the accident occurred.) The pilots of the other departing airplanes did not report any crosswind-related issues or difficulties.[38]

1.10.4 DEN Wind Sensing, ATCT Wind Displays and Reporting

DEN's main ASOS sensor is located east of the main terminal building, near the center of the airport (about 2.4 miles southeast of the accident site), at a height of about 33 feet agl. (LLWAS sensor #14 is located by the ASOS sensor near the center of the airport at a height of 110 feet agl.) As previously stated, the ASOS samples wind direction and speed every second and continuously computes and records various wind averages, including gust information. ASOS wind information is recorded and disseminated in the airport's surface weather observations and ATIS reports.

DEN's LLWAS-NE^{++} system continuously evaluates wind speed and direction information collected by the airport's 32 LLWAS remote sensors, and, if windshear and/or microburst conditions exist, alerts are generated and displayed to air traffic controllers on the RBDT in the DEN ATCT. Wind information recorded by the LLWAS sensor #2 is displayed on the RBDT as the AW. The AW is a running 2-minute average of airport wind direction and speed recorded by sensor #2, with wind gusts, which is updated every 10 seconds and is displayed on

[36] Although departing pilots had the option of requesting a runway more favorably aligned with the wind, DEN ATCT personnel stated that such requests were rare and usually occurred when the crosswind exceeded 30 knots or when windshear alerts were in effect.

[37] Of the seven airplanes that received takeoff clearances, two were departing from runway 25, two were departing from runway 34L, and three (including the accident airplane) were departing from runway 34R.

[38] During this time, DEN arrivals were landing on runways 35L and 35R; there were no crosswind-related reports from any of the arriving pilots.

the DEN ATCT RBDTs. The LLWAS sensor #2 is about 3,310 feet northeast of the approach end of runway 34R, at 110 feet agl.

Pilots departing DEN obtain general wind information from the ATIS broadcast by the DEN ATCT ATIS before taxiing for takeoff. Additionally, the DEN ATCT local controllers provide departing pilots with runway-specific wind information when they issue the flight's takeoff clearance. The controllers obtain the runway-specific wind information (as well as windshear and/or microburst information, when applicable)[39] from the RBDT in the ATCT, which is configured to display wind information[40] recorded by the LLWAS sensor closest to the departure end of each departure runway for which that controller is responsible. If a runway is also being used for arrivals, the RBDT will display both approach and departure runway end wind information. (As previously stated, the DEN ATCT RBDTs also display the AW.) Figure 5 is an exemplar photograph of a DEN ATCT RBDT wind display. (It does not represent the winds present during the accident sequence.)

Figure 5. An exemplar photograph of a DEN ATCT RBDT wind display set up to show arrival and departure wind information for runways 34R, 34L, and 07/25. On the display, the runway 34R departure wind information is on the second line, identified as "34RD." The AW is displayed directly above the runway 34RD information. Note: the wind directions and speeds displayed in this photograph do not represent the winds on the night of the accident.

On the night of the accident, the DEN ATCT local controller who issued the accident flight's takeoff clearance was responsible for departures from runways 34L, 34R, and 25. His RBDT displayed runway 34R departure wind information generated by LLWAS sensor #3 (winds from 270° at 27 knots), which he issued to the accident pilots with their takeoff clearance.

[39] Low-level windshear advisories were in effect at DEN at the time of the accident; however, no windshear events were recorded for runway 16L/34R. A windshear event indicating a 20-knot increase in windspeed near the approach ends of runways 25 and 35R was recorded about 3 minutes before the accident.

[40] The wind values displayed on the RBDT are the averages of three consecutive 10-second wind averages from the applicable LLWAS sensor.

The AW that would have been displayed directly above the runway 34R departure wind information on the RBDT at the time of the takeoff clearance would have shown the wind from 280° at 35 knots, gusting to 40 knots.

DEN ATCT Order 7110.11B, "Standard Operating Procedure," Paragraph 2-1-6, *Operational Wind Sources*, Subparagraph b, states, in part:

> Departures. Issue LLWAS centerfield wind[[41]] to departures. Runway departure-end wind information may [be] issued in lieu of centerfield wind in accordance with FAAO 7110.65, [Paragraph] 3-1-8.b.2(b), Low Level Windshear Advisories.

Because no low-level windshear advisories were in effect for runway 34R the night of the accident, the provision allowing departure wind information to be issued in lieu of centerfield wind in accordance with FAA Order 7110.65, Paragraph 3-1-8.b.2(b), did not apply.

The DEN ATCT local controller did not provide the AW to the accident pilots when he issued their takeoff clearance; rather, he issued the runway 34R departure end wind information, which in this case was reported by LLWAS sensor #3. It was common practice for DEN ATCT controllers to issue departure runway end winds to departing aircraft.[42]

Official guidance regarding the use of low-level windshear and microburst detection systems is contained in FAA Order 7210.3, "Facility Operation and Administration," Chapter 10, Paragraph 10-3-3, and states, in part:

> Prior to operational use of LLWAS facilities, a letter to airmen shall be published explaining, at a minimum, the location and designation of the remote sensors, the capabilities and limitations of the system, and the availability of current LLWAS remote sensor wind information if requested by the pilot. A new letter to airmen shall be issued whenever changes to the above minimum criteria or system upgrades/modifications are made.
>
> …LLWAS airport wind information appearing on the tower LLWAS display may be used in place of the…ASOS automated display wind information.
>
> Facility managers may designate the use of displayed wind information oriented to the threshold end of the runway in lieu of airport winds where LLWAS expanded network systems…are installed, if deemed operationally advantageous.

The letter to airmen described above provides for the dissemination of information that the pilot may need about the LLWAS, including the possible availability of additional details about wind conditions. Additionally, the existence of a letter to airmen allows ATC facility managers to authorize air traffic controllers to issue threshold winds rather than or in addition to ASOS wind information if deemed operationally advantageous. No such letter to airmen had

[41] Centerfield wind and AW are used interchangeably throughout FAA documents; therefore, the terms are considered synonymous for the purposes of this report.

[42] NTSB staff submitted a written request to the FAA about the DEN ATCT controllers' practice of providing departing pilots with departure wind information instead of the AW information as indicated in their published document. The FAA's response did not adequately reconcile this procedural discrepancy.

been published for DEN ATCT.[43] The DEN ATCT controllers were issuing runway departure end winds on the evening of Continental flight 1404's runway excursion.

1.11 Flight Recorder Information

1.11.1 Cockpit Voice Recorder

The accident airplane was equipped with a solid-state Fairchild Model A 100S CVR, serial number (S/N) 00526, designed to record at least the most recent 30 minutes of cockpit audio information. The CVR was sent to the NTSB's laboratory in Washington, D.C., for examination, readout, and evaluation. One channel contained audio information recorded by the cockpit area microphone (CAM), and two other channels contained audio information recorded through the radio/intercom audio panels at the captain and first officer positions. A fourth available channel was not used (nor was its use required) on this recording.

The CVR had not sustained any heat or structural damage, and the audio information was extracted from the recorder normally, without difficulty. The accident CVR contained good quality[44] audio information. The recording started at 1748:05 and continued uninterrupted until 1818:27, when electrical power ceased during the accident sequence.[45] A transcript was prepared of the 30-minute, 22-second recording and is available in appendix B.

1.11.2 Flight Data Recorder

The accident airplane was equipped with an L-3 Communications Fairchild Model FA2100 solid-state FDR, S/N 00478. The FDR was sent to the NTSB's laboratory for readout and evaluation; it was received in good condition, and the data were extracted normally from the recorder.[46] The FDR recorded more than 300 parameters of airplane data; 58 parameters that were considered relevant to this accident were verified and examined. The relevant parameters included acceleration (vertical, lateral, and longitudinal), heading, air and ground speed, control wheel and column position, rudder pedal position, flight-control (elevator/aileron/rudder/stabilizer/slat/spoiler) positions, engine parameters, thrust reverser status (arm advisory/deployed/unlocked), landing gear weight on wheels, drift angle,[47] brake-pedal application and pressure, and speed-brake handle position.[48]

[43] The investigation revealed that LLWAS-related letters to airmen are typically not readily available to pilots.

[44] The NTSB uses the following categories to classify the levels of CVR recording quality: excellent, good, fair, poor, and unusable. A good quality recording is one in which most of the flight crew conversations can be accurately and easily understood.

[45] The airplane was still moving when the CVR stopped recording.

[46] Data were collected until the FDR stopped recording when electrical power ceased during the accident sequence.

[47] Drift angle is the difference between the airplane's heading and its ground track. A positive drift angle means that the airplane is drifting to the right because of a crosswind blowing from the airplane's left to its right.

[48] Although the FDR also recorded wind speed and direction, those values are not valid when the airplane is on the ground and therefore are not addressed in this report.

1.11.3 Optical Quick Access Recorder

The accident airplane was equipped with a Penny + Giles Controls Optical quick access recorder (QAR), S/N 86974-003. A QAR is an unregulated, noncrash-protected airborne data recorder that records flight data as specified by the operator. QAR data are typically used by an operator to monitor the health and performance of the airplane and its systems as well as in the operator's flight data monitoring program. The accident QAR was recovered in good condition and sent to the NTSB's laboratory in Washington, D.C., for examination, readout, and evaluation. In this case, the data recorded by the QAR (including heading, ground speed, flight path acceleration, and engine information) did not provide any information pertinent to the investigation that had not already been obtained from the FDR.

1.12 Wreckage and Impact Information

1.12.1 Description of Wreckage, Tire Marks, and Ground Scars

Examination of the accident runway and wreckage path revealed visible tire marks[49] that veered off the left side of runway 34R on a heading of about 330° about 2,632 feet down the runway. The airplane came to rest on a magnetic heading of about 315° and a postcrash, fuel-fed[50] fire ensued.

More specifically, examination of runway 34R revealed two sets of tire marks that began about 1,910 feet north of the runway's approach threshold and initially straddled the runway centerline. The tire marks were consistent with the accident airplane's left and right main landing gear tires; they continued on a straight track along the runway centerline for about 60 feet and then began to arc to the left. A third tire mark, consistent with the right nose landing gear tire, appeared about 2,015 feet north of the runway's approach threshold, and another tire mark, consistent with the position of the left nose landing gear tire, appeared shortly thereafter. The left and right main landing gear tire marks turned to ground scars/ruts when the tires left the runway pavement and continued onto the grass, snow, and dirt on the left side of the runway. (No distinct ground scars or ruts associated with the nose landing gear were identified.) Figure 6 is an aerial photograph showing tire skid marks veering left from the runway centerline to the edge of the runway pavement and ground scars continuing from the runway.

The two sets of ground scars continued away from the runway across the ground in a north-northwesterly direction. Across taxiway WC, the main landing gear tire marks were measured about 14 feet apart. After crossing the taxiway, ground scars continued for an additional 70 feet, then disappeared at the edge of a drop in terrain. The left and right main landing gear ground scars reappeared later and were joined by two adjacent ground scars, consistent with the engine nacelles. The ground scars continued across an airport service road, converging into one ground scar (about 20 feet wide at its widest point) and continuing to the main wreckage. Debris located within this ground scar included torn metal and other materials; tubing, hoses, and wires consistent with engine components and accessories; the right main

[49] For the purposes of this report, the term "tire mark" refers to a black rubber transfer mark caused by relative motion between the tire and the runway or taxiway surface.

[50] The right-wing fuel tank was breached during the accident.

landing gear assembly; and portions of the left main landing gear. Figure 7 is an aerial photograph showing the tire tracks and ground scars between taxiway WC and the service road.

The airplane fuselage was resting on the ground and was broken into two (forward and aft) sections at a point near the landing gear wheel wells. The right side of the fuselage exhibited fire damage, the most extensive of which occurred in the center section of the fuselage near the wing and engine area. Portions of the fuselage materials (skin and structural frames) in this area, especially those below the top of the passenger windows, were significantly fire-damaged or missing completely.

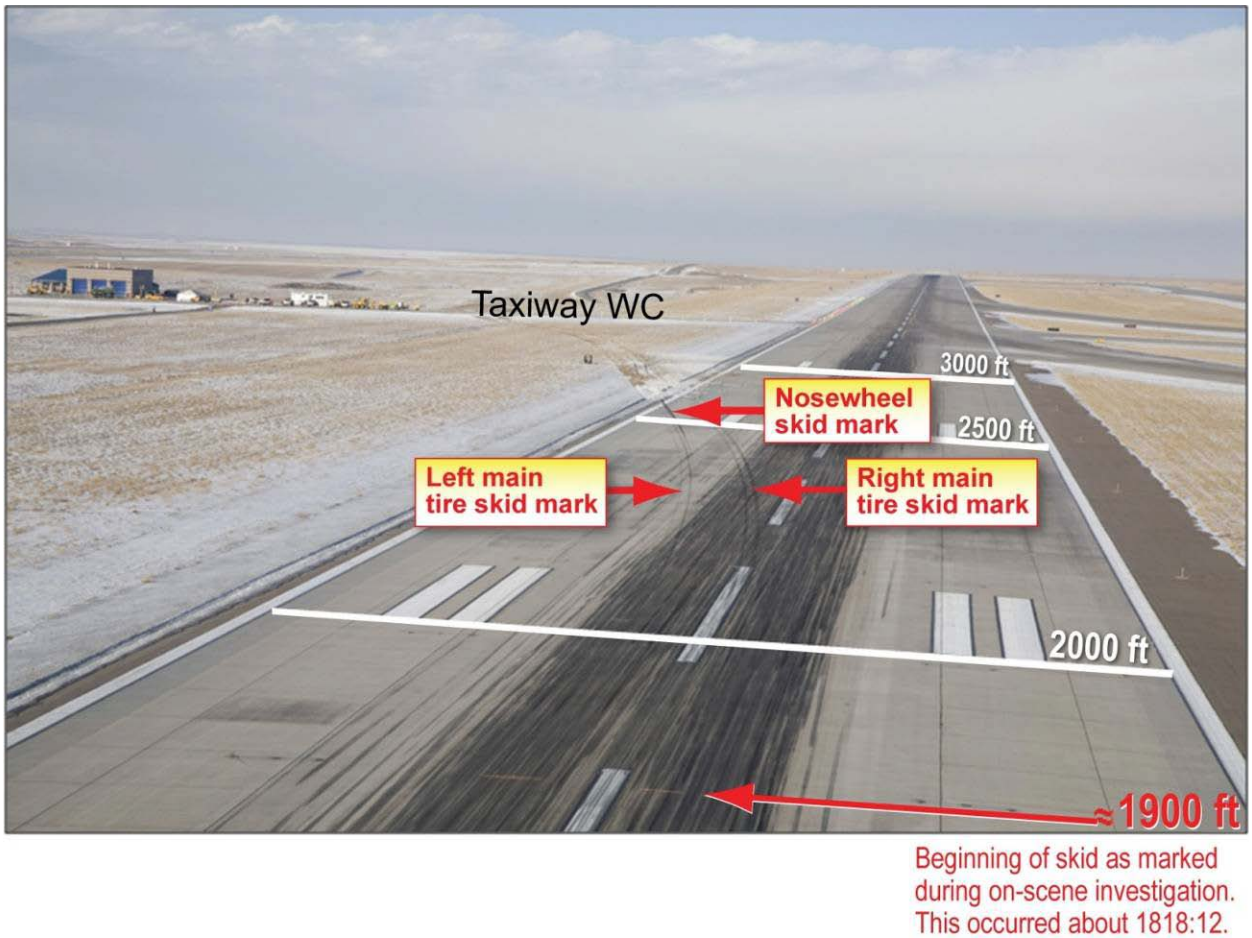

Figure 6. Aerial photograph (facing north-northwest) showing the tire skid marks veering left from the runway centerline to the edge of the runway pavement and the ground scars continuing from the runway. The distance from the approach runway threshold is shown in feet, and taxiway WC is depicted.

Both main landing gear assemblies had separated from the airframe.[51] The nose landing gear was found folded aft and impacted into the lower fuselage. The tires had entered the main electrical equipment compartment (E/E) through the E/E door and frame, lodging on the edge of

[51] Postaccident examination of the main landing gear assemblies revealed that, in both cases, the fused trunnion bolt had separated at the forward trunnion link. These bolts are designed to fail in this location to allow for a controlled main landing gear breakaway under certain conditions.

the doorframe. The structure between the nose gear wheel well and the E/E door was found crushed upward and around the displaced nose landing gear strut. Both the forward and the left side E/E racks were found displaced upward.

Both wings were largely intact and remained attached to the fuselage; however, they were significantly damaged by impact and, in the case of the right wing, postimpact fire. The left engine had separated from the left wing. The empennage was intact and exhibited little damage.

Figure 7. Aerial photograph (facing west-northwest) of the tire tracks and ground scars between taxiway WC and the service road. Note: the tire tracks and ground scars are interrupted where the terrain dropped off; shortly after the tire tracks reappear, engine ground scars begin.

1.12.2 Postaccident System/Component Examinations

1.12.2.1 Nosewheel Steering

The nosewheel steering control cable was found broken during the on-scene inspection of the nosewheel steering control system; the cable had separated in an area near the horizontal pulley that is mounted on the right side of the lower steering plate. According to Boeing, a cable break at this location may result in the nose gear rotating to the left about 7°. NTSB laboratory examination indicated the separation of the cable was due to overstress forces applied to a worn region of the cable after the airplane left the runway. There was no evidence of preaccident cable failure. The investigation revealed that the worn cable had a residual strength that was nearly double the maximum force that could have resulted from the pilot's use of the nosewheel steering tiller. Continuity of the nosewheel steering system between the tiller and the exposed cable was verified.

1.12.2.2 Flight Controls

Examination of the airplane's rudder, aileron, and elevator control systems revealed no evidence of a preimpact flight control malfunction or anomaly. Rudder control system continuity between the rudder pedals at both pilot positions and the aft rudder control quadrant was verified, and postaccident examination of the airplane's rudder control system components revealed no evidence of preimpact anomaly. In addition, the FDR-recorded rudder deflections were consistent with rudder deflection calculated from recorded pedal and yaw damper inputs.

1.12.2.3 Brake Assemblies

Information from the FDR indicated that the airplane's brakes were off (no pressure to the brakes) during the takeoff roll until about 3 seconds after the airplane departed the runway, at which time brake system pressure was simultaneously applied to the left and right main landing gear brakes. The NTSB's postaccident examination and functional testing of the accident airplane's brake system components revealed no anomalies that would have affected the directional control of the airplane during the takeoff roll. Examination of the main landing gear tires revealed only normal wear; there were no flat or scuffed surfaces (typical evidence of a dragging brake) on any of the tires.

1.12.2.4 Powerplants

According to FDR data, the engines spooled up to the desired takeoff power, and no engine anomalies were noted during the takeoff roll while the airplane remained on the runway. About 3 seconds after the airplane departed the runway, the FDR recorded movement of both throttles to idle, and, about 3 seconds later (at 1818:24), the FDR recorded deployment of both engines' thrust reversers. Although the FDR recorded subsequent throttle-lever movements consistent with an attempt to increase reverse thrust, it did not record a corresponding increase in either engine's power setting because of engine damage sustained during the excursion. Postaccident examination of the engines revealed no indications of any preimpact engine case uncontainment or fire.[52] The fan blades in both engines were present and exhibited varying degrees of damage consistent with engine rotation throughout the accident sequence.

1.12.2.5 Crew Seats

On-scene examination showed that both pilots' seats and an occupied aft-facing flight attendant jumpseat that was mounted to the bulkhead wall between the cabin and the cockpit were damaged during the impact sequence. The passenger seats and the two occupied flight attendant jumpseats in the aft cabin exhibited no impact-related damage. The three damaged crew seats were removed from the airplane's forward section and transported to the NTSB materials laboratory for disassembly and further examination.

[52] The inboard cowl on the right engine did exhibit fire and heat damage consistent with the postimpact fire that occurred on the right side of the airplane.

Examination of the pilots' seats revealed that the seat bottoms were deformed in a downward direction, with the seat height adjustment webs failing (where pins were engaged) so that the seats "bottomed out." Further, the restraint harness anchor points at the fronts of both seat bottoms were fractured in an upward direction; materials laboratory examination showed that the upward fracture surfaces were consistent with overstress fractures. The pilots' seats were designed to meet the structural requirements of 14 CFR 25.561, which specified that the seat must withstand static forward loads of 9 G,[53] static downward loads of 6 G, and static upward loads of 3 G. (For additional information on airplane seat certification requirements, see section 1.18.2.)

Examination of the forward flight attendant's jumpseat revealed that the seat pan was broken at the seat's pivot plane, with the forward edge of the seat hanging downward at an angle of about 135° from the seat back. NTSB materials laboratory examination of the fracture surfaces identified a manufacturing defect in the right-side pivot plate and identified areas of fatigue, as well as overload, cracking in the seat's pivot plate. This jumpseat, like the pilots' seats, was certificated to meet the static load requirements of 14 CFR 25.561. (According to Continental's maintenance program, flight attendant jumpseats are lubricated and operationally tested every 575 flight hours and have general visual and harness operations checks every 4,000 flight hours. A thorough inspection/seat restoration is performed every 8,000 flight hours. According to maintenance records, the most recent flight attendant jumpseat lubrication and operational test was completed on October 7, 2008, and the most recent thorough inspection was completed in July 2007.)

1.12.3 Aft Galley Latch Bracket

One of the aft galley drawers became loose during the accident sequence and was found on the galley floor near an aft-facing flight attendant jumpseat. (This flight attendant jumpseat was not occupied during the accident sequence.) Examination of the area revealed a separated aft galley compartment latch plate. The latch plate had been affixed to the galley by adhesive, with no mechanical connection. A review of records from the original manufacturer of the galley, Airplane Products Company,[54] revealed that this design had satisfactorily completed load testing in 1993.

In September 2009, B/E Aerospace published Service Bulletin (SB) 25-30-0436, titled "Repair Scheme of Debonded Workdeck Extrusion for G4B Galley 45104000-1 on Continental Airlines B737-500 Aircraft," which specified a method for mechanically attaching latch plates to the galley on Continental's 737-500 airplanes. Neither B/E Aerospace nor Boeing was able to provide NTSB investigators with information regarding the numbers and types of galleys using similar attachment methods for galley restraints.

1.13 Medical and Pathological Information

About 1945 on December 20, a blood sample was collected from the captain by medical personnel at the hospital where he was admitted and received treatment for injuries sustained in the accident. A portion of this sample was sent to the FAA's Civil Aerospace Medical Institute for

[53] One G is equivalent to the acceleration caused by the Earth's gravity (32.174 feet/second^2).

[54] Airplane Products Company was subsequently acquired by B/E Aerospace.

toxicological testing. The sample tested negative for ethanol and a variety of legal and illegal drugs.[55] The first officer, whose injuries were less serious, was treated at a different hospital and released the night of the accident. On December 21, in accordance with Continental's drug and alcohol testing program, the first officer submitted a urine sample, which the airline sent to an independent diagnostic laboratory for postaccident drug testing. The sample tested negative for drugs of abuse.[56]

A review of accident-related medical records, passenger questionnaires, and other statements revealed that the most serious injuries occurred among occupants, including the captain, who were seated in the forward portion of the airplane and were related to the back/spinal column.[57] Documented minor injuries were sustained by passengers who were seated throughout the airplane and included sprains, strains, bruises, contusions, aches and pains, minor whiplash, and smoke inhalation. For additional information regarding injuries and survival factors, see section 1.15.

1.14 Fire

There was a significant postcrash fire, which was mostly located on the right side of the airplane.[58] All of the airplane occupants had evacuated when the ARFF units arrived at the accident site about 5 minutes after the accident occurred. (For additional information regarding the evacuation, see section 1.15.) ARFF personnel extinguished the exterior fire on the right side of the airplane; firefighters entered the cabin from the forward and aft exits with hoses and fought the interior cabin fire.

1.14.1 Emergency Response

1.14.1.1 Initial Notification

Because of the darkness and the location of the wreckage (in an area of lower elevation on the airport), DEN ATCT personnel were not immediately aware of the accident. However, beginning at 1818:42, DEN ATCT received radio calls from the pilots of several airplanes on the airport reporting the accident. When ATC personnel could not establish radio contact with the accident airplane, at 1819:03 the DEN ATCT CIC picked up the CrashNet system handset and notified the DEN ARFF stations[59] of the crash. The CIC initially provided ARFF personnel with

[55] The captain's blood sample was tested for ethanol and the following drugs: amphetamines, opiates, marijuana, cocaine, phencyclidine, benzoadiazepines, barbiturates, antidepressants, antihistamines, meprobamate, methaqualone, and nicotine.

[56] The first officer's urine sample was tested for the following drugs of abuse: marijuana, cocaine, opiates, phencyclidine, and amphetamines. Because the sample was obtained after the 8-hour window had passed, ethanol testing was not conducted.

[57] The first officer also complained of back pain after the accident.

[58] Very little fuel was recovered from the right wing, and about 4,700 pounds of fuel was recovered from the left wing.

[59] DEN is a 14 CFR Part 139-certificated airport and has an Index E ARFF capability. DEN has four ARFF stations, which are staffed 24 hours a day, 7 days a week. The Denver Fire Department ARFF Division has a staff of 99 firefighters assigned to DEN to provide emergency services for the airport and the surrounding area. All firefighters are trained to Emergency Medical Technician–Basic level. In addition, paramedics from Denver Health Medical Center are stationed at the airport at all times. Ambulance service is provided through Denver Health and may be supplemented by other companies in the Denver metropolitan area.

an incorrect accident location ("off of runway 34R at [WB]")[60]; however, he subsequently relayed the correct accident location to DEN airport ground operations personnel. Additionally, at 1819:50, the DEN ATCT local controller contacted airport ground operations personnel on the local control frequency and advised them "…aircraft departure…off 34R, exited the runway at WC, appears to be on fire immediately adjacent to the firehouse." DEN ATCT repeated the accident location information to DEN airport ground operations again about 15 seconds later, and DEN airport ground operations relayed the revised information to the ARFF crews. Figure 8 is an aerial photograph of the DEN airport with the runways, relevant taxiways, ARFF stations, and accident location identified.

Figure 8. Aerial photograph of the DEN airport with the runways, relevant taxiways, ARFF stations, and accident location identified.

1.14.1.2 ARFF Response

ARFF station #1 is on the southwest side of the DEN terminal area and was closest to the originally reported accident location. According to ARFF station #1 responders, as they drove toward that location, they saw a small jet airplane near the intersection of taxiways F and WB. The responders stated that, as they determined that this airplane was not the accident airplane, operations personnel relayed the corrected accident site information, and the responders continued to drive north to that location. According to the DEN ARFF assistant chief, the trucks

[60] Taxiway WB and runway 34R did not intersect. Taxiway WB is about 1 mile south of taxiway WC.

from ARFF station #1 were delayed “less than a minute” while examining the airplane at taxiway F before proceeding north on runway 34R.

ARFF stations #2 and #3 were located farthest from the originally reported accident location (to the northeast and east-southeast, respectively). According to the ARFF responders from these stations, they initially drove towards the originally-reported accident location when they left their stations. However, they received the revised accident location information while they were en route, and their travel routes and times were such that their response time to the accident site was not adversely affected.

ARFF station #4 was located closest to the actual accident site. However, ARFF station #4 responders stated that when the emergency vehicles left the station, they took the most expeditious route to reach the originally-reported accident location (west on taxiway WC to taxiway D); unfortunately, this took them farther away from the actual accident site. They stated that they did not see the accident airplane, which was located just north of the station in an area of lower terrain on the opposite side of the station from the garage doors. After the ARFF responders were en route, airport operations personnel provided the correct accident location. During postaccident interviews, ARFF station #4 responders stated that, when they were given the correct accident location, they were still unable to see the accident airplane, but they could see multiple emergency response vehicles farther south, so they drove south to meet them. When they met up with the other ARFF trucks as those trucks drove north to taxiway WC, the ARFF station #4 responders turned around again and proceeded with the other ARFF trucks to the accident site.

1.15 Survival Aspects

According to postaccident interviews, although the flight attendants were not able to communicate with the pilots immediately after the airplane came to a stop, they promptly ordered an evacuation when they saw fire outside the airplane. Because the fire was observed outside the right side of the airplane, only the three exits on the airplane’s left side (forward, aft, and overwing) were used during the evacuation.[61] Postaccident statements indicated that the lead flight attendant, who had been seated on a forward jumpseat, operated the left forward exit, the two aft-seated flight attendants operated the left aft exit, and an exit-row passenger operated the left overwing exit. The three flight attendants and two deadheading flight crewmembers assisted the evacuating passengers, blocking access to the right-side exits and directing passengers to less congested exits for maximum efficiency. Flight attendant statements indicated that passengers seemed frightened but were responsive to instructions, and the evacuation progressed quickly and smoothly. The flight attendants and deadheading flight crewmembers ensured that all of the passengers were safely evacuated before they exited the airplane themselves. The lead flight attendant stated that when she observed the others checking the cabin area, she checked on the accident captain and first officer, who were still in their seats in the cockpit. She stated that although both pilots were injured, they exited the airplane without assistance. All airplane occupants had exited and moved away from the airplane before the fire entered the airplane cabin.

[61] The exit doors, escape slides, and emergency lighting system functioned normally during the evacuation.

Once outside the airplane, crewmembers and passengers with less serious or no injuries assisted others up a hill to ARFF station #4. When they reached ARFF station #4, the airplane occupants were triaged and received medical treatment as needed from ARFF emergency medical technicians and on-airport paramedics. The more seriously injured individuals were transported to local hospitals by ambulance, while others were transported to the terminal area by bus.

1.16 Tests and Research

1.16.1 Airplane Performance Studies

The NTSB conducted an airplane performance study to determine the accident sequence based on the available data sources, including the airplane's FDR, DEN ATCT Airport Movement Area Safety System (AMASS), various weather information services, and information collected during the on-scene portion of the investigation.

1.16.1.1 Airplane Performance

Data from several selected FDR parameters were used to identify the pilots' control inputs during the takeoff roll and the excursion across the grassy area left of runway 34R. Data were collected until the FDR stopped recording at 1818:27. The performance study's evaluation of the FDR data showed that engine performance and acceleration appeared consistent with a normal takeoff until just after the airplane departed the runway. The evaluation also showed that the airplane's flight control surfaces responded to the captain's inputs appropriately and that the airplane responded appropriately to the control surface movements.

The performance study's evaluation of FDR data showed that, as the airplane accelerated through about 50 knots, a magnetic heading of about 346° (referred to hereafter in this report as the "baseline heading") kept it tracking the runway centerline. (This baseline heading differed from the runway's magnetic heading of 350°, in part because the airplane cants slightly into the wind on its landing gear during crosswind operations.) Evaluation of the FDR data further showed that, by 1818:07, as the airplane accelerated above 70 knots on the runway, the pilot had applied about 30° of left-wing-down control wheel (aileron) input, about 0.75° of airplane-nose-up control column, and about 4° of right rudder pedal input (about 32 percent of the rudder pedal's available forward motion). The airplane tracked the runway centerline until 1818:12, when the airplane's heading, which had been varying between the baseline heading and about 1° right of that heading, began to move rapidly left.

FDR data showed that, between 1818:12 and 1818:14, the airplane's right rudder deflection, which had been oscillating between its near-neutral and near-maximum positions,[62] transitioned back to a near-neutral position. Additionally, at this time, the control wheel transitioned from about 20° of left-wing-down input to a right-wing-down control wheel input of more than 80°.[63] The performance study showed that the accident airplane departed the runway at 1818:17 at a speed of about 110 knots. FDR data showed that the pilots did not begin to reduce

[62] The near-maximum position corresponded to about 88 percent right rudder pedal input.

[63] During postaccident interviews, the captain told investigators that he added right-wing-down aileron inputs because he was concerned about keeping the airplane upright on the uneven terrain off the left side of the runway.

engine power (leading to the activation of the autobrake system) until about 3 seconds after the airplane left the runway. The airplane reached a maximum speed of about 120 knots before it began to decelerate. The airplane had just crossed taxiway WC and was decelerating through about 90 knots when electrical power to the FDR (and CVR) ceased. Just before it stopped recording, the FDR recorded a 3 G spike in vertical load factor.

The NTSB integrated the FDR-recorded accelerations to create an accurate depiction of the ground path for the accident airplane while determining the acceleration biases needed to match AMASS data and measurements taken on-scene. This integration of data provided a context for the CVR comments and a set of accelerometer biases for the NTSB's wind extraction efforts. (See figure 9.)

1.16.1.2 Estimations of Wind Conditions

The NTSB used available data (measured FDR data and airplane acceleration biases determined from the ground path integration) to estimate the winds that were present during the accident sequence. (Boeing also estimated the wind conditions that were present during the accident sequence, using several different wind estimation methods, which produced results similar to those obtained by the NTSB.) The NTSB's wind extraction results estimated that the winds at the time of the accident varied between 30 and 45 knots from the west, resulting in an almost direct crosswind for runway 34R and a crosswind component that varied from 29 to 45 knots. A peak gust of 45 knots occurred at 1818:12, about the same time the FDR recorded the right rudder pedal beginning to move aft from a position about 72 percent of its available forward travel, reaching a near neutral position at 1818:13.75. The first recorded main landing gear tire skid marks are also estimated to have occurred about this time. Figure 10 shows the NTSB's extracted wind speed and direction for the time of the accident (1818:05 to 1818:15).

Performance calculations indicated that the airplane's rudder was capable of producing enough aerodynamic force to offset the weathervaning tendency created by the winds the airplane encountered during the accident takeoff roll.

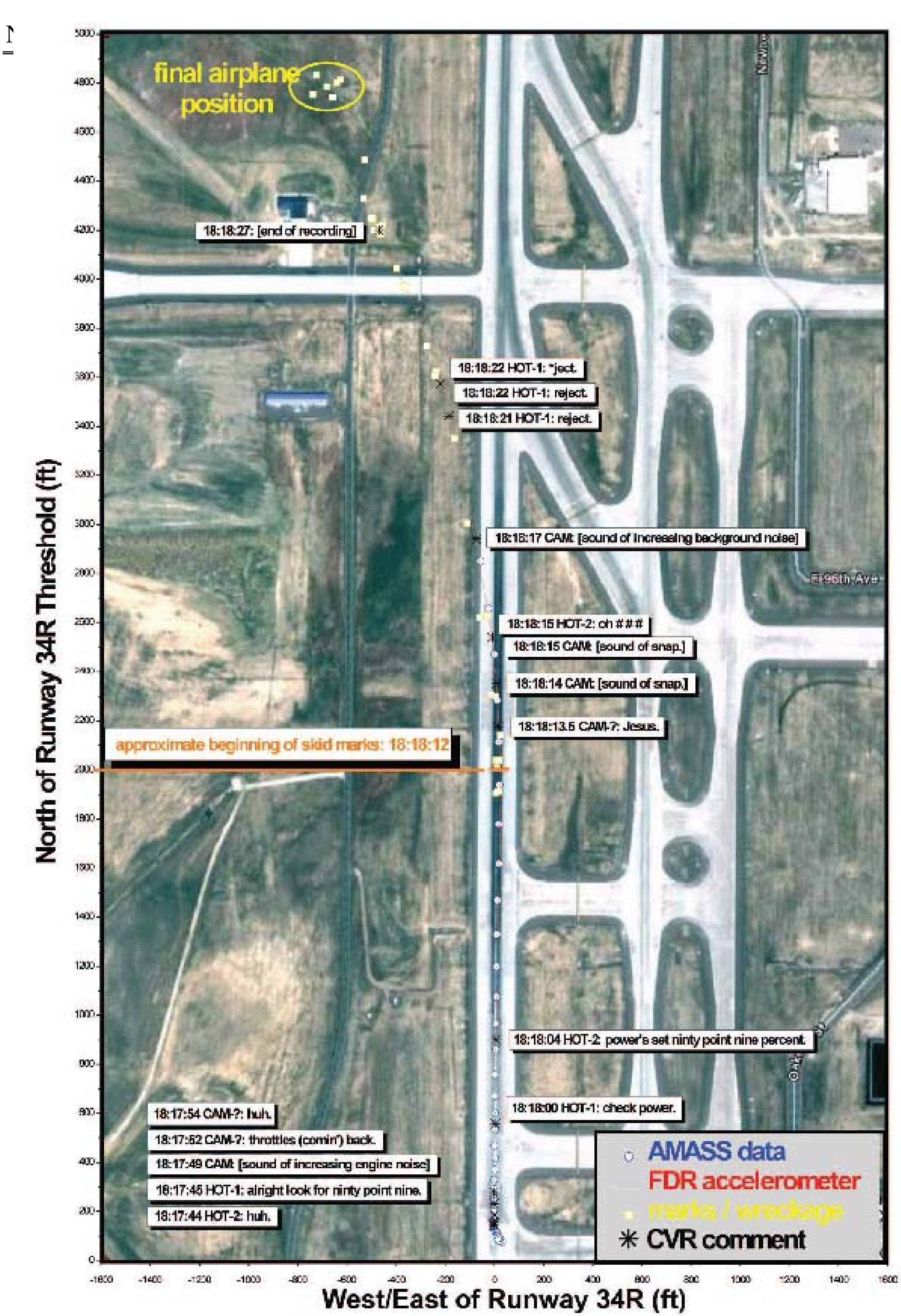

Figure 9. The results of the NTSB integration with CVR comments and ground marks/wreckage information overlaid on an aerial photograph of the pertinent airport features.

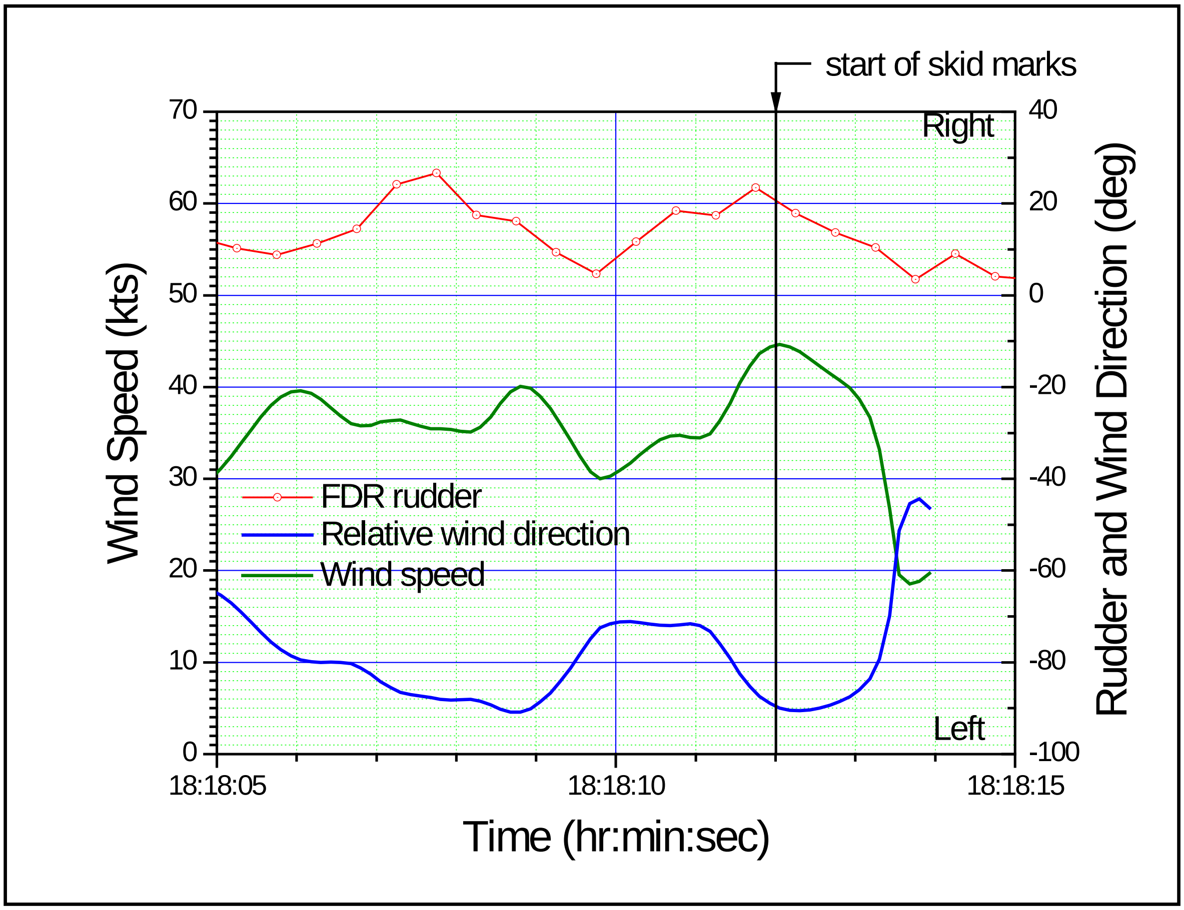

Figure 10. Graph showing the NTSB's extracted wind speed and direction during the time of the runway excursion (1818:05 to 1818:15), with the FDR-recorded rudder deflection. The time of the first recorded tire skid marks is also shown.

1.16.2 Operational Simulator Study

An NTSB investigative team that included ATP-rated pilots from the NTSB, FAA, Boeing, Continental, and Air Line Pilots Association participated in an operational study at Continental's training center in Houston, Texas.[64] The operational study was conducted to 1) familiarize investigators with Continental's SOP for crosswind takeoffs; 2) evaluate the effect of different simulated crosswind conditions on the subjective difficulty of simulated crosswind takeoffs; and 3) evaluate the effect of varied control inputs on simulator response during simulated crosswind takeoffs.

1.16.2.1 Effect of Simulated Crosswinds on Takeoff Difficulty

After crosswind takeoff procedures were demonstrated by Continental training managers, the simulator was set up to replicate the conditions (for instance, darkness, DEN runway 34R, airplane weight, and outside temperature) of the accident takeoff. The five ATP-rated members of the investigative team then performed crosswind takeoffs with left crosswinds of 0, 25, and

[64] Four of the five ATP-rated participants were type-rated on the 737, and one was a 737-rated Boeing test pilot.

35 knots.[65] The flying pilots were informed about the wind condition before each takeoff and rated the difficulty of each takeoff upon completion.[66] On average, the pilots found these conditions to be "very easy" (the 0-knot crosswind takeoff), "neither difficult nor easy" (the 25-knot crosswind takeoff), and "slightly difficult" (the 35-knot crosswind takeoff).

After completing takeoffs in all four crosswind conditions, some participants stated that the task did not seem that difficult overall. They also stated that the simulator did not accurately reflect lateral forces, nor did it provide as good of a "seat-of-the-pants" feel for wind gusts as an airplane would.

Two of the ATP-rated participants tried to take off with a 60-knot simulated crosswind and were able to do so without "crashing" the simulator. They stated that the 60-knot crosswind required more right rudder correction than the other four crosswind conditions, but they indicated that they felt they had more than enough rudder authority available to accomplish the maneuver.

1.16.2.2 Effect of Varied Rudder Inputs

To evaluate the effect of various control inputs during a simulated 35-knot crosswind takeoff, the five ATP-rated participants performed eight takeoff maneuvers, each of which involved varied actions and control inputs, in the simulator. Investigators found that when they removed their feet from the rudder pedals at an airspeed of 90 knots, the airplane exited the left side of the runway in about 5 seconds. If they resumed making corrective rudder inputs 2 seconds after releasing the pedals, they were able to continue or reject the takeoff and prevent a runway side excursion. If they resumed making corrective rudder inputs 3 seconds after releasing the pedals, however, they were unable to consistently take off or stop the airplane before a runway side excursion occurred. Participants agreed that a 3-second delay in reapplication of corrective rudder inputs resulted in a situation that would be unmanageable for a line pilot.

1.16.2.3 Pilot Response Times

A study published by the British Air Accidents Investigation Branch that examined the time a pilot requires to begin a rejected takeoff after a sudden unexpected event during the takeoff roll[67] found the average response time to be 2.7 seconds, with a range of 1.5 to 4 seconds.[68] The authors cautioned that these results probably represent the minimum time for a pilot to react to an unexpected event requiring a rejected takeoff and take action because the pilots who participated in this study were likely expecting to be confronted with an emergency in the simulator. The authors added that a pilot facing the same emergency in a real airplane could take much longer to respond.

[65] The operational simulator study was conducted before the results of the NTSB's airplane performance study wind estimates were available; as a result, wind gusts to 45 knots were not evaluated in this study.

[66] After each takeoff, the flying pilot rated the subjective difficulty of the maneuver on a scale of 1 to 7, with 1 being "very easy," 2 being "moderately easy," 3 being "slightly easy," 4 being "neither difficult nor easy," 5 being "slightly difficult," 6 being "moderately difficult," and 7 being "very difficult."

[67] This event involved the freezing of the control column during the takeoff roll, just prior to rotation speed.

[68] *An experiment designed to measure response times of pilots to a locked elevator condition at rotation speed,* Report on the Accident to Bae HS 748 G-BEKF at Sumburgh Airport, Shetland Islands, on 31 July 1979, Appendix 5, *Aircraft Accident Report 1/81* (London: Air Accidents Investigation Branch, Department of Trade, 1981).

1.16.3 Back-Drive Simulation

An NTSB investigative team also conducted a back-drive simulation using Boeing's multi-purpose engineering cab (M-CAB) simulator and FDR data from the accident airplane. This simulation used FDR data to drive the M-CAB simulator to recreate the cockpit environment that the accident pilots experienced during the accident sequence, including the cockpit visual scene, the flight control inputs, and the airplane accelerations. Because of the nature of a back-drive simulation, participants were unable to provide control inputs or sense control input forces. In addition, it should be noted that all participants were familiar with the circumstances of this accident before participating in the simulation.

In general, simulation participants reported that they were surprised by the magnitude of the rudder inputs and the abrupt shift in heading before the airplane departed the runway. Participants generally agreed that the captain's large right rudder inputs were understandable given the strong and gusty left crosswind for which he was compensating. They considered it likely that the captain would have been able to keep the airplane on the runway if he had continued making significant right rudder inputs when the airplane veered left; however, he did not. (Several participants stated that they wanted to add right rudder to counter the airplane's sudden leftward movement.) The participants were puzzled by the captain's use of the nosewheel steering tiller and his right control wheel input.

1.17 Organizational and Management Information

At the time of the accident, Continental Airlines, Inc., operated a fleet of 368 airplanes in scheduled domestic and international air carrier flight operations out of 4 hub airports.[69] About 70 percent of Continental's fleet was 737-series airplanes; the remainder of the fleet consisted of Boeing 757, 767, and 777 airplanes.

1.17.1 Crosswind Training and Guidance

1.17.1.1 Continental's Crosswind Guidance

Federal regulations (14 CFR 25.237, "Wind Velocities") for airplane certification require manufacturers of transport-category airplanes to demonstrate during flight tests that the airplane is safe for takeoff and landing on a dry runway with a crosswind component of at least 20 knots. (The regulation does not address gusting crosswinds.) The actual crosswind component demonstrated by a manufacturer during certification flight tests depends upon the wind conditions available at the time of certification testing. As a result, manufacturers sometimes use performance analyses to establish supplemental guidelines that involve wind speeds exceeding those actually demonstrated for a particular airplane type or variant. The regulations do not require manufacturers to establish a maximum crosswind operating limitation for either takeoff or landing. Neither the demonstrated crosswind nor any supplemental guideline is necessarily

[69] Continental's hub airports were located in Houston, Texas; Boston, Massachusetts; Newark, New Jersey; and Guam.

considered limiting for pilots in the operation of an airplane (although they are often considered by operators in the development of crosswind guidelines for pilots).[70]

During flight certification testing, Boeing demonstrated crosswind takeoffs in the 737-300 and -500 with 36- and 31-knot crosswind components, respectively. In accordance with an agreement with the FAA, Boeing published a demonstrated value of 35 knots for 737-300/-400/-500s without winglets.[71] In addition, during flight tests for wingleted 737-500 and -800 variants, Aviation Partners Boeing (the manufacturer of the winglets installed on the 737) demonstrated operations in 22- and 33-knot crosswinds, respectively.

In addition to publishing demonstrated crosswind values, Boeing has provided its operators with some crosswind component guidance figures that exceed demonstrated values. Through airplane performance analysis, Boeing has determined that all variants of the 737 have the aerodynamic capability to take off in at least a steady-state, 40-knot direct crosswind on a dry runway. Based on this analysis, Boeing published a uniform supplemental crosswind takeoff guideline of 40 knots for all variants of the 737.

According to Continental's 737 fleet manager, the company reviewed Boeing's 40-knot crosswind guideline and other crosswind guidance materials for 737 airplanes and selected what it considered to be a conservative crosswind guideline of 33 knots for takeoff on a dry runway,[72] and it published this number in 2008 as an operational guideline for all of the 737 variants in its fleet.[73]

1.17.1.2 Continental's Operational Data on Crosswind Takeoffs

After the accident, Continental used data obtained from its operational database to measure crosswind components 7 seconds after takeoff[74] for all 940,000 recorded fleet departures[75] and determined that 250 of those departures (about 0.03 percent) encountered a crosswind of 25 knots or greater and 62 (about 0.01 percent) encountered a crosswind of 30 knots or greater. Looking only at the 250,327 departures involving 737-500 airplanes, Continental found that 76 departures (about 0.03 percent) encountered a crosswind of 25 knots or greater and 4 (about 0.002 percent) encountered a crosswind of 30 knots or greater.

[70] Demonstrated crosswind values can be, but rarely are, determined to be limiting during certification flight testing; however, Boeing has not established crosswind limitations for any of its airplanes.

[71] Similarly, Boeing demonstrated crosswind takeoff values of 31 to 36 knots for the 737-600/-700/-800 models and published a demonstrated value of 36 knots for those 737 models without winglets.

[72] The 33-knot value corresponded to the demonstrated crosswind value documented in the Aviation Partners Boeing publication titled *Airplane Flight Manual Supplement for the Boeing 737-800-3 with Aviation Partners Boeing Blended Winglets*.

[73] Before its selection of a uniform 33-knot dry runway crosswind takeoff guideline for all of its 737 airplanes, Continental had used a 35-knot guideline for some variants of the 737 (the -700 and -800 versions).

[74] According to Continental personnel, because Continental's airplanes were typically between 100 and 200 feet agl (consistent with the height of most LLWAS sensors) 7 seconds after takeoff, this sampling was reasonably representative of the observed winds at the time of takeoff.

[75] These 940,000 departures represented about 8 years' worth of operations, from 2001 to 2009.

1.17.1.3 Continental's Crosswind Training

Continental's flight training program provided pilots with an opportunity to experience crosswind takeoffs and landings in flight simulators during recurrent training every year; however, the crosswind components involved in routine recurrent training sessions were typically much lower than 30 knots.[76] The company's 2004/2005 recurrent flight training included takeoffs and landings in strong crosswind (a 35-knot component) as an area of special emphasis; the captain successfully completed this training. Continental used a 737-500 Full-Flight Simulator (FFS) in its Houston facility for 737 pilot simulator-based recurrent training during the 2004/2005 training year.[77] As a result of this investigation, Continental discovered that its FFS atmospheric model software allowed for only steady state wind inputs—no gusting winds—below 50 feet agl. Before this discovery, Continental's simulator instructors were unaware that the simulator would not apply gusty winds below 50 feet agl, regardless of their manual inputs to the system.

1.18 Additional Information

1.18.1 Previously Issued Mountain-Wave-Related Safety Recommendations

On March 3, 1991, United Airlines flight 585, a 737, N999UA, crashed during its approach to land on runway 35 at the Colorado Springs Municipal Airport (COS), Colorado Springs, Colorado.[78] As a result of its investigation of this accident, on July 20, 1992, the NTSB issued Safety Recommendations A-92-57 and -58 to the FAA regarding the need for increased data regarding the potential for aviation hazards associated with the intense, localized weather disturbances that sometimes occur on the leeward side of mountain ranges:

> Develop and implement a meteorological program to observe, document, and analyze potential meteorological aircraft hazards in the area of Colorado Springs, Colorado, with a focus on the approach and departure paths of the Colorado Springs Municipal Airport [COS]. This program should be made operational by the winter of 1992. (A-92-57)
>
> Develop a broader meteorological aircraft hazard program to include other airports in or near mountainous terrain, based on the results obtained in the Colorado Springs, Colorado, area. (A-92-58)

In its October 8, 1992, response, the FAA indicated that it agreed with the intent of these recommendations and planned to address the issues through interagency research programs with the National Oceanic and Atmospheric Administration's (NOAA) Forecast Systems Laboratory and/or NCAR. However, the FAA indicated that, because of budget constraints and other

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[76] During the 2008/2009 recurrent training year, for example, pilots performed crosswind takeoffs with crosswind components ranging from 4 to 14 knots.

[77] Continental's FFS does not include a winglet increment; however, as discussed earlier, Boeing's aerodynamic data showed that the winglets have a negligible effect on the airplane's crosswind performance.

[78] For additional information, see *United Airlines Flight 585, Boeing 737-291, N999UA, Uncontrolled Collision With Terrain for Undetermined Reasons, 4 Miles South of Colorado Springs Municipal Airport, Colorado Springs, Colorado, March 3, 1991*, Aircraft Accident Report NTSB/AAR-92/06 (Washington, DC; National Transportation Safety Board,1992).

program priorities, work on these projects would likely be delayed until fiscal year 1995. The NTSB's response urged the FAA to reevaluate its program priorities and to more immediately address these issues, and the FAA subsequently accelerated implementation of its research plans. In a September 14, 1993, letter, the FAA indicated that it had tasked NOAA with planning and conducting a study of mountain-induced wind phenomena and their effect on aviation operations and developing a related long-term pilot awareness initiative. As a result of these actions, on January 4, 1994, the NTSB classified Safety Recommendations A-92-57 and -58 "Open—Acceptable Response."

In December 1995, the FAA advised the NTSB that it had scaled back the original plan because of budget constraints but still planned to complete the following three products: 1) a pilot training manual on the impact of mountain-induced aeronautical hazards on aircraft operations; 2) the COS data collection and baseline experiment for a terminal area detection system for mountain-induced turbulence hazards; and 3) a final report with recommendations from this research on the viability of developing a prototype prediction, detection, and display system for these hazards. Pending further information, on March 20, 1996, the NTSB classified Safety Recommendations A-92-57 and -58 "Open—Acceptable Alternate Response."

In an April 3, 1998, letter, the FAA described the following actions it had completed to improve the safety of flying in mountainous areas:

The FAA, NOAA, and NCAR published AC 00-57 to provide information on hazardous mountain winds and their effects on flight operations near mountainous regions.

NOAA and NCAR personnel collected data on the intensity and direction of wind flows at COS from January through March 1997, when mountain-induced activity was known to be prevalent[79] and would publish a report on the findings.

NOAA and NCAR would analyze the COS data and complete a report by September 1998.

The FAA further emphasized the importance of the data that had been gathered, stating, "while the FAA is not able to continue this program to the extent originally planned, I believe that the work accomplished does satisfy the overall intent of these recommendations." Subsequent agency communications revealed that the FAA had initiated programs to study the potential for terrain-induced turbulence in other locations, including Juneau, Alaska. Based on the FAA's actions and ongoing efforts, the NTSB classified Safety Recommendations A-92-57 and -58 "Closed—Acceptable Action" on March 25, 2002, and April 24, 2001, respectively.

1.18.2 Airplane Seat Certification Requirements

The cockpit seats in the accident airplane were designed to meet the structural requirements of 14 CFR 25.561,[80] which specified that the seats must withstand static forward

[79] The data was gathered using one Doppler light distancing and ranging unit; three wind profilers with radio acoustic sounding systems; anemometers; an instrumented airplane that traversed the landing and takeoff flightpaths; six surface meteorological stations; an infrasonic laboratory; and PIREPs.

[80] Title 14 CFR 25.561 was published in the *Federal Register* on December 24, 1964, and was subsequently amended on April 8, 1970 (amendment 25-23); May 17, 1988 (amendment 25-64); and July 29, 1997 (amendment 25-91.)

loads of 9 G, static downward loads of 6 G, and static upward loads of 3 G.[81] On May 17, 1988, the FAA adopted Amendment 25-64 to Part 25, which established a requirement for more stringent crashworthiness standards for transport-category airplane seats. The rule change required a variety of new seat strength tests, including a 16-G dynamic test, which supplemented the earlier static test requirements for seats in newly-certificated airplanes. (Amendment 25-64 affected only seats installed in airplanes with type certification dates after the effective date of the rule; seats installed in existing airplane types, including the 737-500, were not affected by the rule change. This amendment was codified in 14 CFR 25.562.)

Also on May 17, 1988, the FAA published Notice of Proposed Rulemaking (NPRM) 88-8, "Retrofit of Improved Seats in Air Carrier Transport Category Airplanes," which proposed to require all seats (pilot, flight attendant, and passenger) in transport-category airplanes used in Part 121 and 135 operations to comply with the improved crashworthiness standards contained in Amendment 25-64. However, because industry comments revealed seat production and supply and guidance-material issues, the FAA postponed final adoption of the NPRM-proposed amendment.

By the late 1990s, 16-G airplane seats were routinely being produced and certificated. In 1998, the FAA held a public meeting to open renewed discussion regarding the adoption of NPRM 88-8. As a result of this meeting and additional analysis, in 2005, the FAA issued a final rule (the "retrofit" rule), Amendment 121-315, which required that all newly-manufactured transport-category airplanes that were type certificated after January 1, 1958, be equipped with passenger and flight attendant seats that meet the dynamic impact requirements of 14 CFR 25.562 by October 27, 2009. Because cockpit seats and their supporting floor structures are significantly different structurally from passenger and flight attendant seats and their supporting structures, the FAA exempted cockpit seats from the retrofit requirements of Amendment 121-315.

[81] The seat manufacturer's records showed that the required structural tests were successfully conducted for this model seat in June 1986.

2. Analysis

2.1 General

The captain and first officer were properly certificated and qualified under Federal regulations to act in their respective roles during the accident flight and were experienced in the accident airplane. There was no evidence that the pilots had any condition (medical, behavioral, toxicological, or fatigue-related) that might have adversely affected their performance during the accident flight.

The accident airplane was properly certificated, equipped, and maintained in accordance with federal regulations, was dispatched in accordance with industry practices, and was within weight and cg limits.

No evidence indicated any preaccident failure of the accident airplane's powerplants, structures, or systems, including the nosewheel steering system.

The flight attendants acted appropriately when they initiated an emergency evacuation using only the exits on the left side of the airplane because of fire on the right side of the airplane. All passengers were successfully evacuated before fire entered the cabin.

Although there was some initial confusion about the location of the accident, the timeliness of the emergency response was not a significant issue in this accident. The firefighting activities conducted by the DEN ARFF crews were effective in suppressing the exterior and interior fires.

The following analysis discusses the pilots' actions, training, and experience; air traffic controllers' obtaining and disseminating wind information; runway selection and use; crosswind training; simulator modeling; crosswind guidelines and limitations; certification and inspection of crew seats; and galley latches.

2.2 Accident Sequence

The accident flight's departure began routinely. The pilots were instructed to taxi to runway 34R for departure, and they did so without incident. The DEN ATCT local controller's departure clearance indicated wind from 270° at 27 knots (which resulted in a 26.6-knot crosswind for runway 34R). Although this wind was significantly stronger than the wind reported by ATIS (280° at 11 knots) 20 minutes earlier, the wind was still within Continental's crosswind guidelines of 33 knots. Further, other airplanes departed on runways 34L and 34R before the accident pilots' departure; the pilots of those departing airplanes did not report any crosswind-related issues or difficulties.[82] The NTSB concludes that, given the wind-related information the pilots had, their decision to proceed with a takeoff on runway 34R as planned was reasonable.

[82] During this time, DEN arrivals were landing on runways 35L and 35R; there were no crosswind-related reports from any of the arriving pilots.

However, the investigation revealed that the wind conditions at DEN were more complex and variable than the pilots realized. A study conducted by NCAR during this investigation revealed that significant mountain wave activity existed in the area on the day of the accident. Although mountain wave conditions often result in hazards to airplanes in flight, FAA AC 00-57 cautions that mountain wave conditions can include "…localized [surface wind] gusts in excess of 50 [knots]…" and that such conditions can also result in a loss of directional control on or near the runway during takeoffs and landings. In this case, the undulating waves associated with the mountain wave activity extended downward and eastward from the mountains and led to occasional strong and gusty winds at the airport's surface. The NCAR study showed widely variable surface winds across DEN airport locations, occasionally resulting in simultaneous indications of very strong winds from the west at one airport location and light winds from the east at another. NCAR's study showed that a particularly strong wind gust (wind speeds as high as 45 knots) moved across the center of the airport, directly crossing the airplane's path around the time of the accident takeoff. The NTSB concludes that mountain wave conditions were present at the time of the accident and resulted in strong westerly winds and very localized, intermittent wind gusts as high as 45 knots that crossed the airplane's path during the takeoff ground roll.

As previously stated, the ATIS-reported wind (280° at 11 knots) was significantly lighter than the departure wind reported by the local controller (270° at 27 knots). These two wind speed reports were based on measurements taken about 20 minutes apart. In addition, the two wind information reports were based on data from different wind sensors at the airport. The wind information that is broadcast by DEN ATIS is recorded by the DEN ASOS sensor, which is located about 2 1/2 miles southeast of the approach end of runway 34R near the center of the airport at a height of 33 feet agl.[83] The departure wind information provided by the DEN ATCT local controller was recorded by LLWAS sensor #3, which is located near the departure end of runway 34R, at a height of 100 feet agl. The AW displayed on the DEN ATCT RBDT was recorded by LLWAS sensor #2, which is located about 3,310 feet northeast of the approach end of runway 34R at a height of 110 feet agl. A review of the wind speeds recorded by these three sensors revealed that the wind information recorded by the ASOS wind sensor generally recorded lower wind speeds than those recorded by the LLWAS sensors and that, for about 4 minutes preceding the excursion, LLWAS sensor #2 recorded the highest wind speeds on the night of the accident. The NTSB concludes that it is likely that the significant difference between the 11-knot winds reported by DEN's ATIS broadcast and the 27-knot wind information provided to the pilots by the DEN ATC local controller with their departure clearance was the result of the timing of the observations, the placement of the wind sensors, and variations in the local wind field caused by the mountain wave winds.

The accident flight was cleared for takeoff at 1817:26, and the takeoff initially progressed normally. However, at 1818:10, the nose of the airplane began to move left. At 1818:13, the nose of the airplane began to move left very rapidly, and the airplane eventually departed the left side of runway 34R at 1818:17. As the airplane continued off the runway, the captain initiated a rejected takeoff; the airplane subsequently came to rest in a field between runways 34R and 34L.

The remainder of this section evaluates the pilots' decisions and actions during the attempted takeoff and after the airplane left the runway.

[83] LLWAS sensor #14 was located near the DEN ASOS sensor.

2.2.1 Attempted Takeoff

The airplane was nearly aligned with the runway centerline when the captain began to advance the thrust levers for takeoff (at 1817:45). The captain stated that, as the airplane accelerated, he shifted the primary focus of his attention from the thrust setting to outside visual references and kept the airplane tracking along the runway centerline. (As the airplane accelerated through about 50 knots, a baseline heading of about 346° resulted in the airplane tracking along the runway centerline.) Meanwhile, according to postaccident interviews, the first officer's attention was primarily focused on monitoring the engine instruments, consistent with company policy. At 1818:04, when the airplane's speed was about 57 knots, the CVR recorded the first officer advising the captain that the engines had stabilized at takeoff thrust. The first officer stated that, after this point, he shifted his attention to monitoring the airspeed so that he could make the standard airspeed callouts, the first of which was at 100 knots.

FDR heading and rudder pedal position data showed that, as the airplane accelerated between 1818:01 and 1818:07, the captain gradually increased the right rudder pedal input to almost 50 percent of its forward range of travel. The captain's advancement of the right rudder pedal during this time was not perfectly smooth, likely because, as the aerodynamic effectiveness of the rudder increased, he was making incremental adjustments in an attempt to find the correct amount of right rudder pedal input to compensate for the variable crosswind as the rudder became effective. The airplane heading moved left by a fraction of a degree at 1818:03 and again at 1818:05, but it returned to the baseline heading each time as the captain continued to advance the right pedal.

At 1818:06.7, the captain applied a large and rapid right rudder pedal input (reaching about 88 percent of the pedal's available forward range)[84] and then promptly began to relax the right rudder pedal input. During this input, the airplane's heading moved a fraction of a degree left of the baseline heading due to the crosswind and then began to move back to the right (about 1/2 second after the peak of the input). The captain continued to relax the right rudder pedal input as the nose of the airplane moved to the right. After the airplane's heading crossed to the right of the runway baseline heading, the captain relaxed the right rudder pedal input further to about 15 percent. Shortly thereafter, the airplane's heading reached about 1° right of the baseline heading and then (at 1818:10.2) began to move back to the left.

The captain likely anticipated the heading change back to the left because he had begun to advance the right rudder pedal again just before this change in the direction of movement occurred. He paused his right rudder pedal input briefly at 53 percent. Then, when the airplane's nose crossed the baseline heading from right to left without slowing, he further advanced the right rudder pedal to 72 percent, reaching this position at 1818:11.75. He began to relax this right rudder pedal input immediately (as he had after reaching the 88-percent input); about that time, the main landing gear tires began to skid on the runway pavement. The leftward change in heading almost stopped at 1818:12.2, but the airplane began to turn rapidly to the left again at 1818:13.2. The captain had been steadily relaxing the right rudder pedal, reaching 36 percent at this time; however, as the airplane began turning rapidly left this time, he abruptly relaxed the

[84] Simultaneous with this rudder application, the captain added left control wheel (aileron) inputs (consistent with a normal crosswind takeoff technique) and a slight aft control column input.

right pedal to its neutral position. Simultaneous with this sudden relaxation (at 1818:13.5), one of the pilots (likely the captain) stated, "Jesus."[85]

The two unusually large (88 and 72 percent) right rudder pedal inputs made by the captain between 1818:06.7 and 1818:13.2 were of similar duration (about 3 seconds for each complete cycle of rudder input and relaxation). As shown in figure 9, these oscillatory right rudder pedal inputs were similar to each other in shape and differed from the smaller, incremental adjustments the captain made earlier in the takeoff roll. The captain's switch to unusually large inputs changed the dynamics of the situation in ways that may have made it more challenging for him to subsequently control the airplane's heading and track the runway centerline. For example, to avoid overshooting the baseline heading after each large right rudder pedal input, the captain had to compensate by relaxing the right rudder pedal more than he would have had to for a smaller rudder pedal advancement. Furthermore, because of slight delays in the effect each rudder pedal adjustment had on the airplane's rate of heading change, the captain had to anticipate the effect of each adjustment ahead of time. This task was very difficult for the captain because of the highly variable and unpredictable nature of the crosswind gusts.

The first of the captain's large right rudder pedal inputs resulted in an apparent overcorrection of the airplane's heading after about 1.5 seconds. Because the captain had no way to distinguish the effect of his inputs from the effect of the variable crosswind component, he likely believed that this large right rudder pedal input exceeded the amount of rudder correction that would be required to compensate for the crosswind. (In fact, the NTSB's airplane performance analysis revealed that the slight overshoot resulted from a decrease in the crosswind component of about 11 knots.)

The airplane's response to his earlier large rudder pedal input likely led the captain to expect that a slightly smaller right rudder pedal input would stop a subsequent left turn and that the correction would again be evident after a slight delay. As a result, the next time the nose of the airplane began to drift left, the captain used a smaller, but still substantial, right rudder pedal input and again relaxed that rudder pedal input in anticipation of a delayed effect. However, this time, the airplane did not respond as he probably expected. Instead of reversing direction after a slight delay, the airplane's left turn only slowed and then rapidly resumed, which led the captain to believe that the airplane was not responding to his rudder input. The NTSB's aircraft performance study indicated that, as the captain began his second large right rudder pedal input, the left crosswind component increased from 30 knots to about 40 knots and that, as he began to relax this rudder pedal input, the crosswind component increased above 40 knots for about 1.5 seconds. (The study showed a peak wind of about 45 knots at 1818:12.) This strong crosswind gust increased the airplane's sideslip angle, significantly reduced the effect of the captain's 72-percent rudder pedal input, and weathervaned the airplane's nose further to the left. The airplane's heading continued to move left of the baseline heading at an increasing rate; however, instead of making another significant right rudder pedal input (the only control input that could have corrected the airplane's leftward veer off the runway), the captain began to make disorganized and ineffective control inputs. For example, while the airplane's nose was moving rapidly to the left, increasing right rudder would be the most effective control strategy, yet the captain completely relaxed the right rudder pedal input. FDR data showed that, after one small,

[85] Although investigators were unable to attribute the comment definitively to either pilot, the sound of the pilot's voice indicates that it was most likely the captain. He would have been acutely aware of the relationship between his pedal inputs and the airplane's heading oscillations, whereas the first officer was primarily monitoring the airplane's airspeed indicator at the time.

abortive right rudder pedal input at 1818:14, the captain stopped making rudder pedal inputs entirely. Simultaneously, he began to apply right control wheel (aileron) inputs (instead of maintaining left control wheel inputs, which would have been appropriate for the left crosswind conditions), and he tried to steer the airplane to the right using the nosewheel steering tiller.[86]

Continental 737 operating manuals state that the nosewheel steering tiller should be used to turn the airplane only at slow taxi speeds (up to about 20 knots) and that rudder pedal steering and inputs to the rudder surface are more effective means of keeping the airplane on the runway centerline during the takeoff roll. The captain told investigators that he used the airplane's steering tiller (to no avail) in a brief, desperate attempt to keep the airplane on the runway.

Although the FDR does not directly record tiller inputs, FDR data, airplane performance analysis, and physical evidence indicate that the captain did, in fact, turn the control wheel and the steering tiller to the right about 2.75 seconds before the airplane ran off the runway, and neither input had a significant effect on the airplane's heading. (Figure 1, in section 1.1 of this report, shows the oscillations in the airplane's heading relative to the baseline heading and the percentage of forward displacement of the right rudder pedal between 1818:01 and 1818:15, ending about 2 seconds before the airplane left the runway.) The captain's use of the nosewheel steering tiller was contrary to company procedures and neither of these late control inputs was an effective method for turning the airplane at high speed. The NTSB concludes that the captain's use of tiller and full right control wheel in the 3 seconds before the excursion likely resulted from acute stress stemming from a sudden, unexpected threat, perceived lack of control, and extreme time pressure.

The comment "Jesus" suggests that, by 1818:13.5, the captain was aware that his second large rudder pedal input and its subsequent relaxation were not reversing the direction of the airplane's turn as the first large rudder input cycle had. However, the captain did not immediately apply another large right rudder pedal input; rather, he relaxed the rudder pedal to its neutral position. Findings from the NTSB's operational study of simulated takeoffs in a steady 35-knot direct crosswind in a 737-500 simulator suggested that, if the captain had renewed vigorous application of right rudder pedal by 1818:14, he would likely have been able to counteract the airplane's left turn and keep the airplane on the runway. (Although it was not possible to replicate the gusty crosswind conditions that affected the accident airplane, the success of the captain's first large rudder pedal input and relaxation thereof indicates that he might have been able to counteract the airplane's left-turning motion.) However, the NTSB's operational study also showed that it was probably too late for him to prevent an excursion by 1818:15. (The airplane ran off the left side of the runway about 1818:17.) Several ATP-rated pilots who participated in postaccident flight and engineering simulator studies of the accident takeoff (four of whom had 737 type ratings) concurred with this analysis.

Postaccident review of Continental's operational flight data for crosswind takeoffs that was collected during about 8 years of operation indicated that it is rare for Continental's pilots to encounter crosswind components of 30 knots or more. The data showed only 62 such occurrences (4 of which were in 737-500 airplanes) in 940,000 takeoffs. Takeoffs in gusty winds were not specifically identified. Because operational flight data indicate that winds as strong as

[86] During postaccident interviews, the captain explained that he input right aileron because he was concerned about keeping the airplane upright in the terrain on the left side of the runway and that he reached for the nosewheel steering tiller in a final effort to keep the airplane on the runway.

those that the accident pilots experienced on the night of the accident are extremely rare, an individual pilot encountering such strong and gusty winds would have little or no past experience on which to draw during the encounter. The NTSB concludes that the unexpectedly strong and gusty crosswinds the airplane encountered as it accelerated during the takeoff roll made maintaining directional control during this takeoff a more difficult control task than the captain was accustomed to dealing with; however, had the captain immediately reapplied significant right rudder pedal input as the airplane was continuing its left turning motion, the airplane would not have departed the runway.

2.2.2 After the Airplane Left the Runway

The airplane departed the left side of runway 34R at 1818:17, and, based on postaccident interviews and FDR data, the pilots began to experience sharp vertical accelerations as the airplane traversed the uneven terrain beyond the edge of the runway. Although it could not be determined how long the captain continued to manipulate the nosewheel steering tiller (tiller position is not recorded by the FDR), FDR data did show that the captain maintained full right control wheel inputs for about 1 second after the airplane left the runway. At 1818:20, the captain began to reduce power, and, about 1 second later, he called for a rejected takeoff. The pilots began to apply the brakes and moved the thrust levers to produce reverse thrust.

Investigators noted that about 5.75 seconds passed from the time it became apparent to the captain that the airplane was going to leave the runway (at 1818:14.25, less than 1 second after the "Jesus" comment and after the captain started making ineffective control wheel and nosewheel steering tiller inputs) to the captain's initiation of a rejected takeoff (at 1818:20). A study published by the British Air Accidents Investigation Branch that examined the time a pilot requires to begin a rejected takeoff after a sudden unexpected event during the takeoff roll found average response time to be 2.7 seconds, with a range of 1.5 to 4 seconds.[87] Based on this research, the captain's initiation of the rejected takeoff procedure occurred about 3 seconds later than average response and about 1.75 seconds beyond the top of the range.

The captain's actions during his final attempts to keep the airplane on the runway were ineffective, but they also delayed him from performing a rejected takeoff. Because of the positioning of the nosewheel steering tiller and the control wheel and the captain's simultaneous use of these two controls, the captain did not have his right hand on the thrust levers during the excursion. The need to reposition his right hand to the thrust levers as the airplane was bouncing along uneven ground also likely contributed to the delay. The NTSB concludes that the captain's initiation of a rejected takeoff was delayed by about 2 to 4 seconds because he was occupied with the nosewheel steering tiller and right control wheel input, both of which were ineffective and inappropriate for steering the airplane.

2.3 Wind Information and Runway Selection

At the time of the accident, mountain wave and downsloping winds were creating significant and variable surface-level winds at different locations across the airport. Because the

[87] *An experiment designed to measure response times of pilots to a locked elevator condition at rotation speed,* Report on the Accident to Bae HS 748 G-BEKF at Sumburgh Airport, Shetland Islands, on 31 July 1979, Appendix 5, *Aircraft Accident Report 1/81* (London: Air Accidents Investigation Branch, Department of Trade, 1981).

strength and variable nature of the wind conditions factored into this accident, the NTSB evaluated the ability of meteorological instruments and ATC system components to accurately discern and disseminate pertinent wind condition information to pilots. The wind's strength and direction are key factors in runway selection by ATC and pilots; therefore, the NTSB evaluated how the known conditions influenced the selection of runway 34R for departures.

2.3.1 Weather Information

2.3.1.1 Mountain Wave Activity and Associated Local Winds

According to FAA AC 00-57, mountain wave activity can result in strong winds and wind gusts across an airport's surface, resulting in directional control challenges for pilots taking off and landing. At the time of this accident, mountain wave and downsloping wind conditions existed in the Denver area, and the strong localized winds associated with these conditions resulted in pulses of strong wind gusts at the surface that posed a threat to DEN operations. The NTSB has previously noted the potential hazard that mountain wave conditions present to airplane operations. As a result of its investigation of the March 3, 1991, accident involving United Airlines flight 585 in Colorado Springs, Colorado, the NTSB issued two safety recommendations asking the FAA to conduct meteorological research and analyze these potential hazards for airplane operations in the Colorado Springs area and other areas with airports located in or near mountainous terrain. As a result of these recommendations, the FAA, with NOAA and NCAR, conducted research and collected data on hazardous mountain winds and published an AC addressing these winds and their effects on flight operations near mountainous regions. In addition, the FAA initiated programs to study the potential for terrain-induced turbulence in other locations, including Juneau, Alaska. Based on these actions, these safety recommendations were classified "Closed—Acceptable Action."

Although the FAA's research satisfied the intent of the earlier safety recommendations, that research focused mainly on the effects of mountain wave conditions on airplanes in flight, rather than airplanes on the ground. There is no indication that the results of that research have been applied by ATC personnel to the consideration of mountain wave wind conditions with regard to runway selection and airport traffic management decisions. This accident investigation showed that DEN ATC personnel did not recognize and account for possible localized and transient mountain wave-induced gusting crosswinds when they assigned departure runways and disseminated wind information on the night of the accident.

Although strong and gusty winds unrelated to mountain wave conditions can occur at any airport, by their nature, mountain wave winds provide a significant risk of very localized, transient, and severe winds. The NTSB concludes that if ATC personnel and pilots operating at airports located downwind of mountainous terrain had sufficient airport-specific information regarding the localized and transient nature of strong and gusty winds associated with mountain wave and downslope conditions, they would be able to make more informed runway selection decisions. Therefore, the NTSB recommends that the FAA conduct research into and document the effects of mountain wave and downslope conditions at airports, such as DEN, that are located downwind of mountainous terrain (including, for example, airports in or near Colorado Springs, Colorado; Anchorage, Alaska; Salt Lake City, Utah; and Reno, Nevada), identify potential mountain-wave-related hazards to ground operations at those airports, and disseminate the results to pilots and airport ATC personnel to allow for more informed runway selection decisions. One source of data that could allow for a better understanding of the local winds on an airport that result from the mountain wave phenomena is the information already recorded by that airport's LLWAS. LLWAS already alerts to windshear conditions, but its ability to alert ATC to gusts or crosswinds could be improved. Therefore, the NTSB further recommends that the FAA archive all LLWAS data obtained from DEN and other airports that experience similar wind conditions and make those data available for additional research and the potential future development of an improved LLWAS algorithm for crosswind and gusty wind alerts on ATCT RBDTs.

2.3.1.2 ATC Recording and Dissemination of Wind Information

The wind information available to the pilots (through the ATIS broadcast and as issued by ATC with the takeoff clearance) likely played a role in the captain's acceptance of the assigned departure runway and takeoff clearance. Although the ATIS information (which was recorded about 7 minutes before the pilots began to taxi for takeoff) indicated an 11-knot crosswind, when the accident airplane reached the departure runway about 10 minutes later, the DEN ATCT local controller provided runway departure end wind information that indicated a 27-knot crosswind. Although the wind speed reported by the local controller was higher than the ATIS wind, it represented a 26.6-knot crosswind component on runway 34R, which was below Continental's crosswind guideline for dry runway conditions (33 knots).

The DEN ATCT local controller who cleared the accident pilots for takeoff obtained the departure wind information from an RBDT at his position in the control tower. Because the DEN ATCT local controller was responsible for traffic departing from all three departure runways (34L, 34R, and 25), the RBDT at his position automatically displayed runway-specific arrival and departure wind information derived from specific, preassigned LLWAS sensors for those three runways. By system design, the departure wind information displayed on the DEN ATCT local controller's RBDT for runways 34L and 34R was derived from LLWAS sensors #9 and #3, respectively. These sensors are located near the departure ends of their respective runways. In the 2 minutes before the DEN ATCT local controller cleared the accident flight for takeoff, the RBDT displayed runway 34L and 34R departure winds ranging from 23 to 27 knots, wind speeds that were reflected in the wind reports the controller issued to departing pilots during that timeframe. When the local controller cleared the accident pilots for takeoff, he reported winds from 270° at 27 knots.

Arrival wind information displayed on the DEN ATCT local controller's RBDT for runway 34R was derived from LLWAS sensor #2, which is located near the approach threshold of that runway. Because sensor #2 was located closer to the portion of runway 34R on which a departing flight's takeoff roll would occur, wind information derived from sensor #2 would likely have provided the most accurate estimate of the crosswind that the accident pilots were likely to encounter during their takeoff roll. In the 2 minutes before the accident flight was cleared for takeoff, the RBDT indicated runway 34R arrival winds from the west at 29 to 39 knots.

When the accident flight was cleared for takeoff, the AW displayed on the local controller's RBDT (directly above the runway 34R departure end wind that the controller provided to the pilots) would have shown wind from the west at 35 knots with gusts to 40 knots when the accident pilots were cleared for takeoff. However, because DEN's wind dissemination system uses sensor #3 for runway 34R departure wind information, the AW information was not transmitted to the departing pilots. Runway 34R approach threshold wind information, which was recorded by LLWAS sensor #2, was also displayed on the local controller's RBDT, and it indicated wind from the west at 34 knots.

There was no requirement for ATC personnel to provide wind information from other sources, nor were there established criteria for controllers to follow in providing alternate wind information. As a result, because DEN's system dictated only that the local controller provide departing pilots with departure wind information from preassigned sensors, the DEN ATCT local controller did not provide the accident pilots with any additional wind information. The NTSB concludes that although the DEN ATCT local controller followed established practices when he provided the accident pilots with the runway 34R departure end wind information with their takeoff clearance, he did not (nor was he clearly required to) provide information about the most adverse crosswind conditions that were displayed on his RBDT; therefore, the pilots were not aware of the high winds that they would encounter during the takeoff roll. Therefore, the NTSB recommends that the FAA modify FAA Order 7110.65 to require air traffic controllers at airports with multiple sources of wind information to provide pilots with the maximum adverse wind component, including gusts, that the flight could encounter.

During its investigation of this accident, the NTSB noted that FAA Order 7210.3 requires LLWAS-equipped airports to publish a letter to airmen, explaining, at a minimum, the following: the location and designation of the remote sensors; the capabilities and limitations of the system; and the availability of current LLWAS remote sensor wind information, allowing pilots to have access to possibly useful information regarding available sources of airport wind information. However, the FAA was not able to produce evidence that a DEN LLWAS-related letter to airmen was published, and no such letter for DEN (or other LLWAS-equipped airports) was easily publically available. The NTSB concludes that if the FAA had published the required letter to airmen describing the sensor locations, operational capabilities, and limitations of the LLWAS at DEN and the accident pilots had been familiar with its content, they might have been more likely to request additional LLWAS sensor wind information when they saw the clouds moving swiftly across their departure path before they accepted their takeoff clearance and/or began their takeoff roll. Therefore, the NTSB recommends that the FAA review the required documentation for all LLWAS-equipped ATCTs to ensure that a letter to airmen has been published and is easily accessible describing the location and designation of the remote sensors, the capabilities and limitations of the system, and the availability of current LLWAS remote sensor wind information on the request of a pilot, in compliance with FAA Order 7210.3.

2.3.2 Use of Runway 34R for Departure

2.3.2.1 Pilot Acceptance of Runway 34R for Departure

During preflight preparations, the captain asked the DEN ramp controller which runway to expect, and the controller advised him to expect runway 34R. When the pilots subsequently contacted the DEN ATCT ground controller for taxi clearance, the controller advised them to taxi to runway 34R, and the pilots acknowledged that clearance. At the time, with the pilots having obtained the departure ATIS winds (from the west at 11 knots), the minimal resultant crosswind component on runway 34Rwould not have prompted the pilots to question the safety of a departure on that runway.

However, as the accident pilots approached runway 34R and changed to the DEN ATCT local control frequency for their departure, the DEN ATCT local controller cleared an airplane that was in position on runway 34R for takeoff, reporting winds from 270° at 27 knots. When asked to repeat the takeoff clearance, the local controller reported winds from 270° at 25 knots.[88] When the preceding airplane began its takeoff roll, the DEN ATCT local controller cleared the accident pilots to taxi into position and hold on the runway. About 1 minute later, the DEN ATCT local controller reported winds from 270° at 22 knots and cleared another airplane for takeoff on parallel runway 34L.[89] Moments later, the accident captain commented, "Looks like…some wind out there."[90] The first officer replied, "Yeah," and the captain added, "Oh yeah look at those clouds moving."

Although the pilots' comments showed that they were aware of the crosswind, they only became aware of the high crosswinds as they approached runway 34R. At 1817:26, the DEN ATCT local controller told the accident pilots that the wind was from 270° at 27 knots and cleared them for takeoff. During postaccident interviews, the accident pilots reported that they were surprised that the updated wind speed was so much higher than the 11-knot winds reported by the departure ATIS. However, the captain determined that the crosswind component was still several knots below Continental's 33-knot crosswind guideline for takeoff on a dry runway, and because he felt confident in his own ability to handle that much crosswind, he proceeded with the takeoff. The captain's confidence in his ability was likely related to the 900 hours he flew, on average, in the 737 annually, during which he got (in his words) "plenty of practice" at crosswind operations. In addition, the captain had performed simulated takeoff and landing maneuvers in sustained direct crosswinds of up to 35 knots during recurrent training. The NTSB concludes that although the departure wind information the captain received with the takeoff clearance from the DEN ATCT local controller indicated that the winds were out of 270° at 27 knots (which resulted in a stronger-than-expected 26.6-knot crosswind component), the reported winds did not exceed Continental's maximum crosswind guidance of 33 knots, and the captain could reasonably conclude that the winds, as reported by DEN ATCT, did not exceed either his or the airplane's crosswind capabilities.

However, the captain was not aware that the AW (which was recorded by LLWAS sensor #2) at the time of the departure clearance indicated almost direct crosswinds at 35 knots with gusts to 40 knots.[91] Although the AW was displayed on the DEN ATCT local controller's RBDT and indicated more adverse wind conditions than the runway 34R departure end winds (including gusting wind conditions in the case of the AW),[92] the controller followed common practice, which dictated that he provide departure end winds to departing pilots.

Because an airplane can be adversely affected by strong and gusty crosswinds at any point during the takeoff roll and liftoff, the wind information provided to departing pilots should reflect the most adverse wind conditions they are likely to encounter at any point along the runway so that they can make the safest takeoff decision. For example, if the accident pilots had

[88] At that time, LLWAS sensor #2, which is located closest to the approach end of runway 34R, was indicating a wind speed of 30 knots.

[89] At that time, RBDT arrival wind for runway 34R was indicating an almost direct crosswind of 36 knots.

[90] At that time, RBDT approach wind for runway 34R was indicating an almost direct crosswind of 39 knots

[91] LLWAS sensor #2 was the only sensor on the airport (LLWAS or ASOS) that could report wind gusts.

[92] In addition, the RBDT arrival wind for runway 34R was indicating an almost direct crosswind of 34 knots.

been advised of the existing AW when they were cleared for takeoff (35-knot crosswind with gusts to 40 knots) instead of the runway 34R departure end information (27-knot crosswind), it is likely that they would have reconsidered their departure on that runway. The NTSB concludes that if the accident pilots had received the most adverse available wind information (which was displayed as AW on the DEN ATCT local controller's RBDT and indicated a 35-knot crosswind with 40-knot gusts), the captain would likely have decided to delay the departure or request a different runway because the resultant crosswind component exceeded Continental's 33-knot crosswind guidelines.

2.3.2.2 ATC Assignment of Runway 34R

According to DEN ATCT and TRACON personnel, ATC management's selection of a runway configuration takes into account factors such as prevailing and forecast weather conditions (including surface winds, winds aloft, and pilot reports) and practical considerations (including runway availability, snow removal activities, and demand or activity). Also, because DEN's operations have a significant effect on the entire NAS, DEN ATC management personnel participate in operational planning teleconferences at national and regional levels to discuss the effect of anticipated airport runway configuration and arrival rates on other traffic within the NAS.

DEN airport had an official runway-use policy (DEN Airport Part 210) that addressed noise abatement procedures; however, this policy did not affect the accident airplane because the 737-500 was not considered a noise-critical airplane. The NTSB concludes that none of DEN's noise abatement procedures affected the accident airplane's departure runway assignment because the 737-500 was not considered a noise-critical airplane.

Basic air traffic procedures for runway selection contained in FAA Order 7110.65 state that, "except where a runway use program is in effect," ATC personnel should use the runway most nearly aligned with the wind unless use of another runway "will be operationally advantageous, or is requested by the pilot." DEN ATC did not have a formal runway-use program; however, according to DEN ATC management personnel, they had an unofficial runway-selection policy, which would use the runway configuration that provided the greatest operational advantage for the airport at crosswind speeds up to 20 knots. This unofficial policy also indicated that DEN ATCT personnel were to consider using a different runway when requested by a pilot or when crosswind speeds exceeded 25 knots.[93] Requests for alternate departure runways were rare at DEN and mostly occurred when crosswinds exceeded 30 knots.[94] On the night of the accident, DEN ATCT had elected to operate in a runway configuration that used runways 34L, 34R, and 25 for departures, all of which were under the control of the same local controller. Although all three of the departure runways were available for the accident flight's departure, DEN ATC assigned the accident pilots runway 34R for departure; this assignment was based primarily on operational considerations such as ground traffic flow and the flight's destination. All of the pilots departing on runways 34R and 34L received similar departure clearance wind advisories in the minutes before the accident, and none of them requested a different departure runway.

[93] As already discussed, when the local controller cleared the accident pilots for takeoff, he reported winds from 270° at 27 knots.

[94] Because ATC personnel are not familiar with the specific crosswind limitations of the airplanes and pilots operating on their airport, pilot requests are often the impetus for alternate runway assignments.

ATC personnel routinely balance operational advantage considerations with other factors (such as crosswind component, runway availability, and weather conditions) in determining runway assignments to optimize safety and avoid delays involved with rerouting ground and/or air traffic. The DEN ATCT local controller who cleared the accident pilots for takeoff on runway 34R with departure winds from 270° at 27 knots was likely not attending to the AWs shown on his RBDT, which indicated westerly winds at 35 knots with gusts to 40 knots. As a result, he likely believed runway 34R to be an appropriate departure runway for the existing circumstances, presumably, in part, because other airplanes had recently departed safely in similar wind conditions.[95] However, if the local controller had noted (and subsequently provided the pilot with) the available AW information, which more accurately reflected the existence and ongoing development of mountain-wave-related, very localized, strong and gusty winds, he may have offered (or the pilot may have requested) a runway more aligned with the wind. Further, the local controller (and/or DEN ATCT management) would likely have selected a runway more aligned with the wind if DEN ATCT had a runway selection policy that explicitly detailed runway assignment procedures for operations in strong crosswinds.

The NTSB concludes that, currently, the DEN ATCT runway selection policy does not clearly account for crosswind components when selecting a runway configuration. Therefore, the NTSB recommends that the FAA require ATCTs to locally develop and implement written runway selection programs that proactively consider current and developing wind conditions and include clearly defined crosswind components, including wind gusts, when considering operational advantage with respect to runway selection.

2.4 Crosswind Training and Guidelines

2.4.1 Crosswind Training

The dynamics of the gusty crosswinds that affected the accident airplane during its takeoff roll directly affected the captain's control inputs. However, the investigation also evaluated the extent to which the captain's past experience and training influenced his actions. Continental records indicated that the captain had successfully completed all company training, which included crosswind takeoffs and landings every year. During a 2004/2005 recurrent simulator training session, he completed a takeoff and landing in a static, direct crosswind of 35 knots. However, the company's 737-500 flight simulators (in which the captain likely accomplished this training) were not programmed to simulate gust effects below about 50 feet above the ground and, therefore, were not capable of replicating the complex disturbances that pilots would experience during takeoffs and landings in gusty surface winds.[96]

[95] Although DEN's unofficial runway selection policy suggests that controllers consider assigning pilots a runway more aligned with the wind when crosswind speeds exceed 25 knots (as they did the night of the accident), there was no requirement for controllers to alter runway assignments under such conditions.

[96] After the accident, Continental stated that its 737-800 flight simulators were programmed to replicate gusty surface winds; however, Continental indicated that it was "the norm" for 737 recurrent training to be performed in 737-500 simulators, and there was no evidence that the accident captain had been trained to perform high-crosswind takeoffs in a 737-800 simulator.

Although during postaccident activities investigators described attempted simulator takeoffs in direct 35-knot crosswinds as only slightly difficult,[97] these assessments did not adequately reflect most real-world, high-crosswind takeoffs because Continental's 737-500 simulators do not incorporate wind gusts. Further, takeoff data obtained from Continental indicated that the company's pilots rarely, if ever, encountered crosswind components greater than 30 knots during actual flight operations. It is unlikely that Continental's pilots were proficient at handling strong and gusty crosswinds like those encountered by the accident pilots during their takeoff roll.

Steering control dynamics are quite different when taking off in steady wind conditions as compared to gusty crosswind conditions. A takeoff in a steady crosswind requires a pilot to compensate for gradual changes in the airplane's tendency to turn into the wind by testing to see how much rudder correction is needed and slowly adjusting to match slow changes in the required amount of rudder correction. The required amount of rudder correction changes relatively slowly and follows a predictable pattern. According to a Boeing study of 737-500 crosswind takeoff performance, the amount of rudder pedal input needed to keep the airplane tracking the runway centerline during a steady crosswind takeoff varies as a function of airspeed and crosswind component, with the amount of rudder correction needed increasing up to a certain airspeed and diminishing gradually thereafter. Although a pilot may identify the proper rudder position by moving the rudder pedals back and forth, or "bracketing" the target position, and observing the effect on the airplane's tracking of the runway centerline, the required amount of rudder correction changes slowly and predictably, so the task is not very difficult.

By contrast, during takeoffs in strong and gusty crosswinds, a pilot must do all of the above while simultaneously compensating for disturbances in heading caused by fluctuations in the magnitude of the crosswind component. In these conditions, it can be more difficult to determine whether a deviation in the airplane's heading is the result of a change in the crosswind component or the slight lag in the effect of a prior rudder input. Airplane control dynamics may also be affected by the magnitude or frequency of pilot control inputs. Although some bracketing of the target rudder position is necessary in both steady and gusty crosswind conditions, bracketing with control inputs that oscillate too much or too slowly when taking off in very strong and gusty wind conditions may increase the risk of pilot confusion about the relationship between control inputs and airplane response. Therefore, wind characteristics and pilot technique may interact to affect the difficulty of a crosswind takeoff.

Increased training in this area could benefit pilots because it could help them identify how wind characteristics may affect airplane response and how pilot technique may affect steering difficulty. However, limitations in existing simulator capabilities are an obstacle to providing pilots with realistic gusty crosswind training. Although much work has been done to improve the fidelity of flight simulators in recent decades, the NTSB is unaware of any recent efforts to improve the fidelity of the wind models used in simulators for the training of gusty crosswind takeoffs and landings.[98] Pilots given the opportunity to practice takeoffs in realistic strong and gusty crosswind conditions would have a chance to identify effective and ineffective

[97] Because the wind estimate results of the NTSB's airplane performance study (which indicated gusty crosswinds of 45 knots) were not available at the time, the attempted takeoffs performed in the operational simulator study did not replicate stronger gusty winds.

[98] Since the NTSB recommended that realistic windshear and microburst wind models be incorporated in flight simulators in the early 1980s, the industry has incorporated such models into pilot training programs.

techniques for steering the airplane in such conditions, thus increasing the likelihood of effective performance. Additionally, such training could help pilots develop a more realistic appreciation of their own abilities and of the potential difficulty associated with crosswind takeoffs in high and gusty winds and about whether to initiate a takeoff in such conditions.

Although pilots should avoid taking off in very strong and gusty crosswinds, real-time pertinent wind information may not always be available; providing pilots with training in how to deal with very strong and gusty crosswinds that they might inadvertently encounter would increase their ability to react appropriately to these situations. If the accident captain, for example, had been exposed to realistic takeoff scenarios involving very strong and gusty crosswinds in a flight simulator during pilot training, he would have been better equipped to compensate for the conditions he unexpectedly encountered during the attempted takeoff that resulted in the accident. If airline pilots were exposed to more realistic gusty surface crosswinds during flight simulator training, they would be able to develop related skills and realistic expectations in a controlled training environment, thus improving their ability to handle extreme surface wind conditions that are inadvertently encountered during real-world operations.

Airplane performance analyses conducted during this investigation provided a high-resolution sample of second-by-second changes in wind speed and direction that occurred during the attempted takeoff. These data represent a complex crosswind condition, the strong and gusty nature of which, according to Continental's operational flight data, is rarely encountered during normal operations and which was evidently very challenging for the accident captain, a highly experienced and skilled pilot. The NTSB concludes that, because Continental's simulator training did not replicate the ground-level disturbances and gusting crosswinds that often occur at or near the runway surface, and it is unlikely that the accident captain had previously encountered gusting surface crosswinds like those he encountered the night of the accident, the captain was not adequately prepared to respond to the changes in heading encountered during this takeoff. Therefore, the NTSB recommends that the FAA gather data on surface winds at a sample of major U.S. airports (including DEN) when high wind conditions and significant gusts are present and use these data to develop realistic, gusty crosswind profiles for use in pilot simulator training programs. The NTSB further recommends that the FAA require 14 CFR Part 121, 135, and 91K operators to incorporate the realistic, gusty crosswind profiles developed as a result of Safety Recommendation A-10-110 into their pilot simulator training programs.

2.4.2 Crosswind Guidelines and Limitations

Although crosswind guidelines and limitations were not a factor in this accident because the winds, as reported to the pilot, were within limits, the NTSB examined the procedures used by manufacturers and operators for establishing such guidelines. Because pilots can encounter strong and gusty wind conditions under many circumstances and at many locations, it is important that they have access to well-researched, validated crosswind takeoff guidance to help them better understand the effects of crosswinds and wind gusts on the airplane. This information would enable pilots to make well-informed decisions when such adverse circumstances are encountered.

Airline operators have historically referred to the maximum demonstrated crosswind published by airplane manufacturers when developing their own operator-specific guidelines. The manufacturers' demonstrated crosswind is not considered limiting for any new airplane type certified by the FAA within the past 40 years; however, most operators adopt crosswind guidelines that do not exceed the manufacturers' demonstrated crosswind. Although Boeing published different demonstrated crosswind values for takeoff on a dry runway for different variants of the 737, Continental adopted a 33-knot guideline for its entire 737 fleet for standardization purposes. Company managers stated that they established the 33-knot guideline based on the maximum demonstrated crosswind component of 33 knots for the wingleted version of the 737-800. This value, published by Aviation Partners Boeing, was lower than Boeing's published maximum demonstrated crosswind component for the 737-500 (35 knots) and the 40-knot "crosswind guideline" published by Boeing for all 737 airplanes. For this reason, it is likely that Continental considered 33 knots to be a conservative number.

The NTSB notes that a manufacturer's demonstrated crosswind is based on the successful accomplishment of three takeoffs and landings by a highly skilled test pilot and reflects the wind conditions that were available to the manufacturer for testing during the certification process. The NTSB also notes that an evaluation of an airplane's crosswind takeoff and landing performance (and perceived handling qualities) in very gusty wind conditions is not required by Federal regulations, nor is the manufacturer required to publish information about the gust factor present during testing. Airplane manufacturers are not required to establish crosswind guidelines that are above the maximum demonstrated crosswind component, and there are no FAA standards for the establishment of such guidelines.

Boeing developed enhanced crosswind guidelines through a self-designed analysis process, which resulted in a uniform dry-runway crosswind takeoff guideline of 40 knots for all 737 variants. However, the desktop simulation that Boeing primarily used in its development of this guideline did not assess the effect of wind gusts on perceived handling qualities or takeoff or landing difficulty. The NTSB concludes that, because there are no standards for the development of enhanced crosswind guidelines for transport-category airplanes, Boeing did not adequately consider the dynamic handling qualities of the 737 during takeoff or landing in strong and gusty crosswinds; it is likely that the enhanced crosswind guidelines developed by other manufacturers are similarly deficient. Therefore, the NTSB recommends that, once realistic, gusty crosswind profiles as asked for in Safety Recommendation A-10-110 are developed, the FAA develop a standard methodology, including pilot-in-the-loop testing, for transport-category airplane manufacturers to establish empirically based, type-specific maximum-gusting-crosswind limitations for transport-category airplanes that account for wind gusts. Further, the NTSB recommends that, once a methodology is developed as asked for in Safety Recommendation A-10-112, the FAA require manufacturers of transport-category airplanes to develop type-specific, maximum-crosswind takeoff limitations that account for gustiness.

The NTSB recognizes that implementation of the preceding recommendations will be a relatively lengthy process involving significant research, and, thus, will involve delays in the safety-enhancing benefits of the limitations. Therefore, the NTSB recommends that, until the actions described in Safety Recommendation A-10-113 are accomplished, the FAA require manufacturers of transport-category airplanes to provide operators with interim crosswind takeoff guidelines that account for wind gusts.

2.4.3 Crosswind-Related Applications for Operational Flight Data

Although valuable information was gained from the investigation of this accident, additional safety benefits could accrue from studying a range of other, less serious events that are routinely recorded by airline onboard recording devices for operational use. For example, operational flight data obtained from Continental during this investigation revealed that only 4 out of 250,327 Boeing 737-500 takeoffs reviewed occurred in crosswind components of 30 knots or greater during the 8 years preceding the accident (and 58 additional events occurred involving other airplanes in Continental's fleet during the same period).

The NTSB notes that the FAA is currently participating in collaborative, proactive, and voluntary safety programs with several airlines involving the collection of operational flight data by onboard flight data recording devices and the subsequent analysis of such data for the identification of trends and potential safety vulnerabilities. Because, in many cases, the operational flight data can be linked to related airport, runway, and/or weather information, the data generated through these safety programs could prove valuable for learning more about the context in which high crosswind component takeoffs are occurring and the extent to which they are a safety hazard. These encounters could be identified by looking for large rudder corrections during the takeoff roll or by using air data to estimate the magnitude of the crosswind component shortly after takeoff.[99] Once identified, high crosswind component takeoffs could be related to archival data from other sources. For example, several airlines (including Continental) are able to match routine weather observations with operational flight data for individual flights. By analyzing the location, timing, and reported weather conditions in which these events are occurring, the FAA should be able to identify additional training or operational strategies for reducing the frequency of such events, thus reducing the risk of crosswind-related runway excursions.

The NTSB concludes that operational flight data from U.S. airlines regarding high crosswind component encounters could help the FAA develop additional strategies for reducing the risk of crosswind-related runway excursions. Therefore, the NTSB recommends that the FAA work with U.S. airline operators to review and analyze operational flight data to identify factors that contribute to encounters with excessive winds and use this information to develop and implement additional strategies for reducing the likelihood of wind-related runway excursions.

2.5 Other Issues

2.5.1 Cockpit Seats

Both pilot seats in the accident airplane failed during the accident sequence. Postaccident examination of the seats revealed that both seats' crotch-restraining-strap attachment points were fractured in an upward direction and that both seat height adjustment mechanisms had failed in a downward direction, "bottoming out" during the impact sequence. These failures indicate that the pilots' seats experienced both upward and downward crash forces in excess of their structural capabilities. Both pilots complained of back injuries after the accident, and medical records indicated that the captain sustained multiple lumbar and thoracic spinal fractures.

In 1988, the FAA adopted a regulatory amendment (to 14 CFR Part 25) that required more stringent crashworthiness standards, including 16-G dynamic tests, for transport-category airplane seats. In 2005, the FAA issued a final rule (Amendment 121-315) that required that all transport-category airplanes with earlier type certifications be equipped (retrofitted) with passenger and flight attendant seats that meet the 16-G dynamic impact requirements (as codified

[99] Operational information provided by Continental indicated that these two variables are highly correlated.

in 14 CFR 25.562) by October 27, 2009. Seats installed in the cockpits of those airplanes are not required to meet those crashworthiness standards. The cockpit seats in the accident airplane were designed to meet the structural requirements of 14 CFR 25.561,[100] which specified that the seat must withstand static forward loads of 9 G, static downward loads of 6 G, and static upward loads of 3 G.[101]

Investigators noted another instance in which the pilot received more serious injuries than other airplane occupants. The captain of the May 9, 2004, American Eagle flight 5401, an Avions de Transport Regional 72-212 that crashed during landing at Luis Muñoz International Airport, San Juan, Puerto Rico,[102] had a fractured L-2 vertebra, whereas all other occupants received minor injuries. The American Eagle flight 5401 captain's seat was certified to the same static test requirements as the cockpit seats in the Continental accident airplane. It is evident that seats meeting improved crashworthiness standards (meeting the requirements of 14 CFR 25.562) would have provided a higher level of safety for the accident pilots. Therefore, the NTSB concludes that the accident pilots' injuries would have likely been lessened or eliminated if their seats had been designed to meet the crashworthiness requirements of 14 CFR 25.562, to which other airplane seats are designed. Therefore, the NTSB recommends that the FAA require cockpit crew seats installed in newly manufactured airplanes that were type certificated before 1988 to meet the crashworthiness standards contained in 14 CFR 25.562.

2.5.2 Flight Attendant Jumpseat

The seat pan on the aft-facing flight attendant jumpseat (a Burns Aerospace model 2501-5) that was mounted on the forward bulkhead between the cabin and the cockpit was also broken during the accident. Examination showed that the left seat pan pivot plate broke, allowing the seat pan to collapse. Although this seat was likely subjected to excessive vertical loads, it is not clear that the failure was purely the result of those loads. The NTSB's materials laboratory identified a manufacturing defect in the right-side pivot plate and resultant preexisting fatigue cracks in both the right- and left-side pivot plates. These fatigue cracks weakened the seat frame, and when the airplane impacted the ground, the cracks extended, further weakening the seat frame and the seat bottom failed.

Although no manufacturing records were available, it is likely that the machining defect was an original manufacturing defect because there was no record or indication of subsequent related maintenance actions that might have resulted in such a defect. Although a review of Burns Aerospace and Continental records indicated that failures of this jumpseat model are not common, the NTSB is concerned that the fatigue cracks in this seat were not detected during the company's routine maintenance tasks or inspections, the most recent of which was completed on

[100] Title 14 CFR 25.561 was published in the *Federal Register* on December 24, 1964, and was subsequently amended on April 8, 1970 (amendment 25-23); May 17, 1988 (amendment 25-64); and July 29, 1997 (amendment 25-91).

[101] The seat manufacturer's records showed that the required structural tests were successfully conducted for this model seat in June 1986.

[102] For additional information, see *Crash During Landing, Executive Airlines (doing business as American Eagle) Flight 5401, Avions de Transport Regional 72-212, N438AT, San Juan, Puerto Rico, May 9, 2004,* Aircraft Accident Report NTSB/AAR-05/02 (Washington, DC: National Transportation Safety Board, 2005).

October 7, 2008.[103] This jumpseat model is widely used in the airline industry, and its failure could result in serious injuries to a cabin crewmember in an emergency situation during which that crewmember would most be needed. Fortunately, in this case, the flight attendant who was seated in the jumpseat when it failed was not seriously injured and was able to subsequently perform critical duties during the evacuation.

The NTSB concludes that a flight attendant jumpseat that is weakened due to undetected metal fatigue could fail under lower-than-expected crash loads and injure a cabin crewmember who might subsequently be needed to perform critical safety duties, such as evacuating passengers. Therefore, the NTSB recommends that the FAA require operators to perform periodic inspections on the Burns Aerospace model 2501-5 jumpseats for fatigue cracks within the jumpseat structure and replace the jumpseat if fatigue cracks are found.

2.5.3 Aft Galley Latch Bracket

During the postaccident documentation of the airplane's aft galley, investigators noted that one of the aft galley drawers, which should have been latched in its compartment for the takeoff, was loose on the floor adjacent to the aft lavatory. Further examination revealed that the compartment latch plate had been affixed to the galley by adhesive, with no mechanical connectors. Unrestrained items (especially heavy items) in this location are particularly hazardous because an aft-facing flight attendant jumpseat is located directly forward of that compartment. (Fortunately, no one was seated on that jumpseat at the time of the accident.)

Records indicated that the galley and its components had satisfied static load requirements during testing conducted by the original manufacturer in 1993.[104] However, unlike mechanical fasteners, adhesive-only fasteners such as the fastener used in the accident galley are susceptible to degradation over time because of exposure to temperature changes, sunlight, chemicals, and other factors. As a result, the performance of an adhesive fastener becomes less predictable with time. In September 2009, B/E Aerospace published SB 25-30-0436, which specified a method for mechanically attaching the latch plate to G4B galleys on Continental 737-500 airplanes. However, compliance with the SB is not required. Additionally, neither Boeing nor B/E Aerospace was able to provide data regarding the use of adhesive fasteners for galley restraints; however, it is possible that there are airplanes outside the Continental 737-500 fleet with galleys that use adhesive attachments whose operators are not aware of SB 25-30-0436.

The NTSB concludes that the adhesive-only fastening method used for the latch plate in the aft galley of the accident airplane and similarly equipped airplane galleys was not adequate for securing galley drawers or other items of mass because it can fail over time and/or with exposure to the elements. The corrective action published in SB 25-30-0436 was not mandatory and applied only to Continental 737-500 airplanes. Because similar attachment methods might be used in other airplanes, the NTSB therefore recommends that the FAA require that operators of

[103] According to Continental's maintenance program, flight attendant jumpseats are lubricated and operationally tested every 575 flight hours and undergo general visual and harness operations checks every 4,000 flight hours. Seat restoration is performed every 8,000 flight hours.

[104] Airplane Products Company, the original manufacturer of the galley, was subsequently acquired by B/E Aerospace.

transport-category airplanes that use galley latches or latch plates secured solely by adhesives that may degrade over time modify the latches to include mechanical fasteners.

3. Conclusions

3.1 Findings

1. The captain and first officer were properly certificated and qualified under Federal regulations to act in their respective roles during the accident flight and were experienced in the accident airplane. There was no evidence that the pilots had any condition (medical, behavioral, toxicological, or fatigue-related) that might have adversely affected their performance during the accident flight.

2. The accident airplane was properly certificated, equipped, and maintained in accordance with Federal regulations, was dispatched in accordance with industry practices, and was within weight and center of gravity limits.

3. No evidence indicated any preaccident failure of the accident airplane's powerplants, structures, or systems, including the nosewheel steering system.

4. The flight attendants acted appropriately when they initiated an emergency evacuation using only the exits on the left side of the airplane because of fire on the right side of the airplane. All passengers were successfully evacuated before fire entered the cabin.

5. Although there was some initial confusion about the location of the accident, the timeliness of the emergency response was not a significant issue in this accident. The firefighting activities conducted by Denver International Airport aircraft rescue and firefighting crews were effective in suppressing the exterior and interior fires.

6. Given the wind-related information the pilots had, their decision to proceed with a takeoff on runway 34R as planned was reasonable.

7. Mountain wave conditions were present at the time of the accident and resulted in strong westerly winds and very localized, intermittent wind gusts as high as 45 knots that crossed the airplane's path during the takeoff ground roll.

8. It is likely that the significant difference between the 11-knot winds reported by Denver International Airport's (DEN) airport terminal information service broadcast and the 27-knot wind information provided to the pilots by the DEN air traffic control local controller with their departure clearance was the result of the timing of the observations, the placement of the wind sensors, and variations in the local wind field caused by the mountain wave winds.

9. The captain's use of tiller and full right control wheel in the 3 seconds before the excursion likely resulted from acute stress stemming from a sudden, unexpected threat, perceived lack of control, and extreme time pressure.

10. The unexpectedly strong and gusty crosswinds the airplane encountered as it accelerated during the takeoff roll made maintaining directional control during this takeoff a more difficult control task than the captain was accustomed to dealing with; however, had the captain immediately reapplied significant right rudder pedal input as the airplane was continuing its left turning motion, the airplane would not have departed the runway.

11. The captain's initiation of a rejected takeoff was delayed by about 2 to 4 seconds because he was occupied with the nosewheel steering tiller and right control wheel input, both of which were ineffective and inappropriate for steering the airplane.

12. If air traffic control personnel and pilots operating at airports located downwind of mountainous terrain had sufficient airport-specific information regarding the localized and transient nature of strong and gusty winds associated with mountain wave and downslope conditions, they would be able to make more informed runway selection decisions.

13. Although the Denver International Airport air traffic control tower local controller followed established practices when he provided the accident pilots with the runway 34R departure end wind information with their takeoff clearance, he did not (nor was he clearly required to) provide information about the most adverse crosswind conditions that were displayed on his ribbon display terminal; therefore, the pilots were not aware of the high winds that they would encounter during the takeoff roll.

14. If the Federal Aviation Administration had published the required letter to airmen describing the sensor locations, operational capabilities, and limitations of the low-level windshear alert system (LLWAS) at Denver International Airport and the accident pilots had been familiar with its content, they might have been more likely to request additional LLWAS sensor wind information when they saw the clouds moving swiftly across their departure path before they accepted their takeoff clearance and/or began their takeoff roll.

15. Although the departure wind information the captain received with the takeoff clearance from the Denver International Airport (DEN) air traffic control tower (ATCT) local controller indicated that the winds were out of 270° at 27 knots (which resulted in a stronger-than-expected 26.6-knot crosswind component), the reported winds did not exceed Continental's maximum crosswind guidance of 33 knots, and the captain could reasonably conclude that the winds, as reported by DEN ATCT, did not exceed either his or the airplane's crosswind capabilities.

16. If the accident pilots had received the most adverse available wind information (which was displayed as airport wind on the Denver International Airport air traffic control tower local controller's ribbon display terminal and indicated a 35-knot crosswind with 40-knot gusts), the captain would likely have decided to delay the departure or request a different runway because the resultant crosswind component exceeded Continental's 33-knot crosswind guidelines.

17. None of Denver International Airport's noise abatement procedures affected the accident airplane's departure runway assignment because the 737-500 was not considered a noise-critical airplane.

18. Currently, the Denver International Airport air traffic control tower runway selection policy does not clearly account for crosswind components when selecting a runway configuration.

19. Because Continental's simulator training did not replicate the ground-level disturbances and gusting crosswinds that often occur at or near the runway surface, and it is unlikely that the accident captain had previously encountered gusting surface crosswinds like those he encountered the night of the accident, the captain was not adequately prepared to respond to the changes in heading encountered during this takeoff.

20. Because there are no standards for the development of enhanced crosswind guidelines for transport-category airplanes, Boeing did not adequately consider the dynamic handling qualities of the Boeing 737 during takeoff or landing in strong and gusty crosswinds; it is likely that the enhanced crosswind guidelines developed by other manufacturers are similarly deficient.

21. Operational flight data from U.S. airlines regarding high crosswind component encounters could help the Federal Aviation Administration develop additional strategies for reducing the risk of crosswind-related runway excursions.

22. The accident pilots' injuries would have likely been lessened or eliminated if their seats had been designed to meet the crashworthiness requirements of 14 Code of Federal Regulations 25.562, to which other airplane seats are designed.

23. A flight attendant jumpseat that is weakened due to undetected metal fatigue could fail under lower-than-expected crash loads and injure a cabin crewmember who might subsequently be needed to perform critical safety duties, such as evacuating passengers.

24. The adhesive-only fastening method used for the latch plate in the aft galley of the accident airplane and similarly equipped airplane galleys was not adequate for securing galley drawers or other items of mass because it can fail over time and/or with exposure to the elements.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the captain's cessation of right rudder input, which was needed to maintain directional control of the airplane, about 4 seconds before the excursion, when the airplane encountered a strong and gusty crosswind that exceeded the captain's training and experience.

Contributing to the accident were the following factors: 1) an air traffic control system that did not require or facilitate the dissemination of key, available wind information to the air traffic controllers and pilots; and 2) inadequate crosswind training in the airline industry due to deficient simulator wind gust modeling.

4. Recommendations

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

> Conduct research into and document the effects of mountain wave and downslope conditions at airports, such as Denver International Airport, that are located downwind of mountainous terrain (including, for example, airports in or near Colorado Springs, Colorado; Anchorage, Alaska; Salt Lake City, Utah; and Reno, Nevada), identify potential mountain-wave-related hazards to ground operations at those airports, and disseminate the results to pilots and airport air traffic control personnel to allow for more informed runway selection decisions. (A-10-105)

> Archive all low-level windshear alert system (LLWAS) data obtained from Denver International Airport and other airports that experience similar wind conditions and make those data available for additional research and the potential future development of an improved LLWAS algorithm for crosswind and gusty wind alerts on air traffic control tower ribbon display terminals. (A-10-106)

> Modify Federal Aviation Administration Order 7110.65 to require air traffic controllers at airports with multiple sources of wind information to provide pilots with the maximum wind component, including gusts, that the flight could encounter. (A-10-107)

> Review the required documentation for all low-level windshear alert system (LLWAS)-equipped air traffic control towers to ensure that a letter to airmen has been published and is easily accessible describing the location and designation of the remote sensors, the capabilities and limitations of the system, and the availability of current LLWAS remote sensor wind information on the request of a pilot, in compliance with Federal Aviation Administration Order 7210.3. (A-10-108)

> Require air traffic control towers to locally develop and implement written runway selection programs that proactively consider current and developing wind conditions and include clearly defined crosswind components, including wind gusts, when considering operational advantage with respect to runway selection. (A-10-109)

> Gather data on surface winds at a sample of major U.S. airports (including Denver International Airport) when high wind conditions and significant gusts are present and use these data to develop realistic, gusty crosswind profiles for use in pilot simulator training programs. (A-10-110)

> Require 14 *Code of Federal Regulations* Part 121, 135, and 91K operators to incorporate the realistic, gusty crosswind profiles developed as a result of Safety Recommendation A-10-110 into their pilot simulator training programs. (A-10-111)

Once realistic, gusty crosswind profiles as asked for in Safety Recommendation A-10-110 are developed, develop a standard methodology including pilot-in-the-loop testing, for transport-category airplane manufacturers to establish empirically based, type-specific maximum-gusting-crosswind limitations for transport-category airplanes that account for wind gusts. (A-10-112)

Once a methodology as asked for in Safety Recommendation A-10-112 has been developed, require manufacturers of transport-category airplanes to develop type-specific, maximum-crosswind takeoff limitations that account for wind gusts. (A-10-113)

Until the actions described in Safety Recommendation A-10-113 are accomplished, require manufacturers of transport-category airplanes to provide operators with interim crosswind takeoff guidelines that account for wind gusts. (A-10-114)

Work with U.S. airline operators to review and analyze operational flight data to identify factors that contribute to encounters with excessive winds and use this information to develop and implement additional strategies for reducing the likelihood of wind-related runway excursions. (A-10-115)

Require cockpit crew seats installed in newly manufactured airplanes that were type certificated before 1988 to meet the crashworthiness standards contained in 14 *Code of Federal Regulations* 25.562. (A-10-116)

Require operators to perform periodic inspections on the Burns Aerospace model 2501-5 jumpseats for fatigue cracks within the jumpseat structure and replace the jumpseat if fatigue cracks are found. (A-10-117)

Require that operators of transport-category airplanes that use galley latches or latch plates secured solely by adhesives that may degrade over time modify the latches to include mechanical fasteners. (A-10-118)

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Adopted: July 13, 2010

5. Appendixes

Appendix A

Investigation and Public Hearing

Investigation

The National Transportation Safety Board (NTSB) was notified about the accident on December 20, 2008, almost immediately after it occurred. A go-team was launched early the next morning. Joining the team in Denver, Colorado, was Board Member Robert Sumwalt and an NTSB Public Affairs representative.

The following investigative groups were formed during this investigation: operations, human performance, air traffic control, survival factors, structures, systems, powerplants, meteorology, airplane performance, and maintenance records. Also, specialists were assigned to conduct the readout of the flight data recorder/quick access recorder and transcribe the cockpit voice recorder at the NTSB's laboratory in Washington, D.C.

In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the NTSB's counterpart agency in France, the Bureau d'Enquêtes et d'Analyses, participated in the investigation as the representative of the State of Design and Manufacture (Powerplants).

Parties to the investigation were the Federal Aviation Administration; Continental Airlines, Inc.; Boeing; Air Line Pilots Association (ALPA); Denver International Airport; General Electric/Société Nationale d'Étude et de Construction de Moteurs d'Aviation (GE/SNECMA); National Air Traffic Controllers Association (NATCA); International Brotherhood of Teamsters; and Aviation Partners Boeing. The NTSB received submissions regarding this accident from Continental, ALPA, Boeing, NATCA, and GE/SNECMA.

Public Hearing

No public hearing was held for this accident.

Appendix B

Cockpit Voice Recorder Transcript

The following is a transcript of the Fairchild Model A 100S cockpit voice recorder installed on the accident airplane, a Boeing 737-500, N18611, which departed the left side of runway 34R during takeoff from Denver International Airport, Denver, Colorado, on December 20, 2008.

LEGEND

CAM	Cockpit area microphone voice or sound source
HOT	Flight crew hot microphone audio voice or sound source
INT	Flight crew intercom voice or sound source
RDO	Radio transmissions from N18611
Ramp	Radio transmission from the Denver ramp controller
GND	Radio transmission from the Denver ground controller
TWR	Radio transmission from the Denver airport tower controller
-1	Voice identified as the captain
-2	Voice identified as the first officer
-3	Voice identified as the female flight attendant
-4	Voice identified as passenger
-5	Voice identified as passenger
-6	Voice identified as gate agent
-7	Voice identified as the ground mechanic
-8	Voice identified as the male flight attendant
-?	Voice unidentified
*	Unintelligible word
#	Expletive
@	Non-pertinent word
( )	Questionable insertion
[ ]	Editorial insertion

Note 1: Times are expressed in Mountain Standard Time (MST)
Note 2: Generally, only radio transmissions to and from the accident aircraft were transcribed.
Note 3: Words shown with excess vowels, letters, or drawn out syllables are a phonetic representation of the words as spoken.
Note 4: A non-pertinent word, where noted, refers to a word not directly related to the operation, control or condition of the aircraft.

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
TIME (MST) SOURCE	CONTENT	TIME (MST) SOURCE	CONTENT
17:48:05 [start of recording/ start of transcript]			
17:48:05	(start of recording)		
17:48:33 CAM-1	cold front.		
17:48:37 CAM-2	its still seventy eight degrees there.		
17:48:43 CAM-1	oh man thirty three *		
17:49:05 CAM-2	the're gunna dead head back to Houston and sit for fifteen hours. looks like a nice-.		
17:49:13 CAM-1	are they Newark-- goin to Lauderdale?		
		17:50:41 RDO-1	do you know what runway for Plains departure?

		17:50:44 Ramp Tower	East gate looks like three four right bravo current departure ATIS.
		17:50:48 RDO-1	thanks.
17:50:52 CAM-2	three four right.		
17:50:55 CAM-2	it's already in there.		
17:50:59 CAM-1	yeah baby. worked out nicely.		
17:51:06 CAM-2	what gate are we going now?		
17:51:09 CAM-2	Charlie thirty seven.		
17:51:23 CAM-1	Denver Approach so it's ah I just curious about the ah.		
17:51:36 CAM-1	Bravo south alpha north. that taxiway to golf foxtrot.		

17:51:54 CAM-1	then we're three four right all the way out to the end.		
17:52:05 CAM-3	hey you've got company.		
17:52:07 CAM-1	dude what's happening what's your name?		
17:52:10 CAM-4	*		
17:52:13 CAM-4	I want to come drive up here.		
17:52:15 CAM-2	can I go sit in your seat you can sit right there.		
17:52:16 CAM-4	okay.		
17:52:18 CAM-1	you're gunna sit here and I'm gunna sit in your seat.		
17:52:21 CAM-4	yeah.		
17:52:21 CAM-2	and it's your leg you're gunna fly.		

17:52:23 CAM-1	why don't you ask your dad first if he wants me to do that.		
17:52:25 CAM-3	he's with his mom.		
17:52:26 CAM-1	or ask your mom if you can drive and I can sit in your seat.		
17:52:29 CAM-4	mommy can I drive?		
17:52:31 CAM-5	I don't mind be careful okay.		
17:52:33 CAM-1	alright but that means I'm sittin' in his seat.		
17:52:35 CAM-5	alright it's nine B.		
17:52:38 CAM-1	((sound of laugh))		
17:52:41 CAM-1	she's just kiddin' I don't think she really wants you to drive.		

17:52:43 CAM-4	yes she does.		
17:52:43 CAM-1	you need to have a drivers license let me see your drivers license.		
17:52:46 CAM-4	I don't have any.		
17:52:47 CAM-1	well then you can't drive.		
17:52:56 CAM-1	he'd had done it too.		
17:52:57 CAM-1	he would have tried it anyways.		
17:53:02 CAM-1	I was expecting his mother to save me.		
17:53:06 CAM-1	no son you can't drive.		
17:53:20 CAM-1	she's probably checkin' you out on the way in.		
17:53:26 CAM	[sound of high low chime]		

17:53:29 CAM-1	that's funny.		
17:53:33 CAM-1	zero nine seven I guess.		
17:53:41 CAM-1	all ready **.		
17:53:49 CAM-1	I don't see any surprises on the departure MSA's ninety two hundred and engine out runway ah three four.		
17:54:04 CAM-1	all other runways standard.		
17:54:09 CAM-2	engine failure after *.		
17:54:10 CAM-2	standard engine out.		
17:54:12 CAM-1	so what have we got here we're fifty three ah fifty four hundred so let's call that ah *...does that sound about right?		
17:54:25 CAM-2	yup.		

17:54:32 CAM-2	flaps five reduced.		
17:54:40 CAM-1	thirty seven--.		
17:54:40 CAM-2	thirty seven forty forty six.		
17:54:42 CAM-1	thirty seven forty forty six.		
17:54:48 CAM-1	set forty--.		
17:54:53 CAM-1	and what do we have here one seventeen.		
17:54:55 CAM-2	two twenty.		
17:54:56 CAM-1	and external *.		
17:55:02 CAM-1	alright so ah heading select up to ten thousand feet level change top bug. did he give us the right runway?		

17:55:09 CAM-2	that's three four right there. here's runway two five. you know there's a chance we can go two five.		
17:55:19 CAM-1	if that's the case then we need to brief the engine out for that.		
17:55:22 CAM-1	watch your legs.		
17:55:24 CAM	sound of trim in motion.		
17:55:31 CAM-2	that's good forty forty six.		
17:55:35 CAM-1	questions comments on the departure.		
17:55:37 CAM-2	nope.		
17:55:38 CAM-1	okay receiving.		
17:55:40 CAM-2	circuit breakers emergency equipment.		

17:55:41 CAM-1	checked.		
17:55:42 CAM-2	flight deck windows locked?		
17:55:43 CAM-1	they're locked.		
17:55:43 CAM-2	oxygen checked set one hundred percent?		
17:55:45 CAM-1	checked one hundred percent.		
17:55:46 CAM-2	IRS selectors?		
17:55:47 CAM-1	there nav.		
17:55:47 CAM-2	hydraulics?		
17:55:48 CAM-1	checked on.		
17:55:48 CAM-2	air conditioning and pressurization?		

17:55:50 CAM-1	it's set for Houston.		
17:55:52 CAM-2	excuse me mode control panel?		
17:55:54 CAM-1	set.		
17:55:54 CAM-2	altimeters and flight instruments are two nine nine three inches and I have sixty three hundred feet set and checked?		
17:55:59 CAM-1	alright ninety three inches and I have sixty three hundred set.		
17:56:03 CAM-2	takeoff config switch?		
17:56:03 CAM-1	checked.		
17:56:04 CAM-2	ground proximity?		
17:56:05 CAM-1	checked.		

17:56:05 CAM-2	speed brake lever down detent?		
17:56:06 CAM-1	down detent.		
17:56:07 CAM-2	parking brake?		
17:56:07 CAM-1	set.		
17:56:07 CAM-2	start levers?		
17:56:08 CAM-1	cut off.		
17:56:08 CAM-2	transponder?		
17:56:10 CAM-1	stand-by good squawk.		
17:56:11 CAM-2	log book ETOPS gear pins MEL?		
17:56:13 CAM-1	checked onboard.		

17:56:14 CAM-2	flight attendant pilot briefing?		
17:56:15 CAM-1	complete.		
17:56:15 CAM-2	receiving aircraft checklist complete.		
17:56:19 CAM-2	I got a lot * #.		
17:56:34 CAM-2	want the APU up?		
17:56:36 CAM-1	what's that? yeah.		
17:57:49 CAM-1	is that another one?		
17:57:50 CAM-2	yeah they bumped up the zero fuel weight it's for two five but I bumped up the zero fuel weight in the ah perf-init. here it comes.		
17:57:58 CAM-1	three four right.		

17:58:05 CAM-1	that's the old two five I'm gunna throw it.		
17:58:12 CAM-2	three four right that's the one we want right?		
17:58:15 CAM-1	yup.		
17:58:16 CAM-2	here's the *.		
17:58:24 CAM-6	Captain are you ready to go?		
17:58:26 CAM-1	check with @ Regina. when she's ready I'm ready		
17:58:28 CAM-6	okay		

17:58:48 PA-1	good evening folks from the flight deck Captain Butler here and first officer Lavang we'd like to add our welcome to flight fourteen zero four service to the Houston Bush Intercontinental Airport. one hour fifty two minutes enroute we don't anticipate any delays out of Denver and the ride should be pretty good all the way to Houston ah they're expecting some weather to blow through later this evening it may or may not impact our arrival but gate charlie thirty seven currently a comfortable seventy two degrees standard clouds winds are out of the south at six knots we do appreciate your business. welcome aboard.		
17:59:20 CAM-6	ready to go?		
17:59:21 CAM-1	check with @ Regina please.		
17:59:23 CAM-6	okay.		
17:59:24 CAM-1	if she's ready I'm ready.		
17:59:26 CAM-1	I already said that once.		

17:59:28 CAM-2	I'm pretty sure you did too.		
17:59:42 CAM-2	we like it shaken not stirred huh?		
17:59:45 CAM-1	depends on what I'm drinkin'.		
17:59:47 CAM-2	coffee.		
17:59:48 CAM-1	I don't have a ah--.		
17:60:00 CAM-1	is it still four on the trim?		
18:00:02 CAM-2	three and three quarters.		
18:00:03 CAM-1	okay alright watch your legs.		
18:00:05 CAM	[sound similar to trim in motion]		
18:00:08 CAM	[sound of single chime]		

18:00:51 CAM-?	it's warm.		
		18:00:54 INT-7	ground to cockpit.
		18:00:56 INT-1	good evening.
		18:00:57 INT-7	good evening dude.
18:00:59 CAM-1	dude?		
		18:01:00 INT-7	hey good evening I just did a walk around we're gunna close that.
18:01:10 CAM	[sound of high low chime]		
		18:01:14 INT-7	okay walk around has been complete all doors access panels have been closed and ramp is ready.
		18:01:20 INT-1	let me run a checklist and I'll be right back with ya.

		18:01:22 INT-7	copy that.
18:01:24 CAM-2	two nine nine seven.		
18:01:26 CAM-1	set.		
18:01:35 CAM-1	alright before start checklist.		
18:01:39 CAM-2	before start seatbelt sign?		
18:01:41 CAM-1	it's on.		
18:01:41 CAM-2	door lights?		
18:01:42 CAM-1	out.		
18:01:42 CAM-2	beacon?		
18:01:42 CAM-1	it's on.		

18:01:43 CAM-2	CDU?		
18:01:43 CAM-1	set.		
18:01:44 CAM-2	reference speeds?		
18:01:45 CAM-1	thirty seven forty forty six set.		
18:01:47 CAM-2	thirty seven forty forty six set.		
18:01:49 CAM-2	fuel?		
18:01:50 CAM-1	release twenty point oh I've got twenty point oh and four pumps on.		
18:01:53 CAM-2	trim?		
18:01:54 CAM-1	three and three quarters zero.		
18:01:55 CAM-2	before start checklist complete. call ‘em?		

18:01:58 CAM-1	actually lets wait.		
18:02:01 CAM-1	* something here.		
18:02:04 CAM-1	not a big hurry we're on-time.		
18:02:16 CAM-2	let's shoot a little air back there it's getting a little stuffy with all that heat.		
18:02:38 CAM-8	now we--.		
18:02:39 CAM-1	that's okay no problem.		
18:02:40 CAM-8	ah eight and ninety nine.		
18:02:42 CAM-1	eight and ninety nine and you're you are? what's your name?		
18:02:45 CAM-8	Al.		

18:02:46 CAM-1	Al Dave.		
18:02:47 CAM-2	I'm Sean.		
18:02:48 CAM-7	Al. nice to meet you.		
18:02:49 CAM-1	you too.		
18:02:51 CAM-8	oh different guys now sorry guys.		
18:02:54 CAM-1	huh that's alright that's the way it works.		
18:02:58 CAM-8	are they dead heading back there?		
18:02:59 CAM-1	yes.		
18:03:00 CAM-8	okay that's why I'm confused sorry.		
18:03:03 CAM-1	alright no problem.		

18:03:05 CAM-2	get you there as soon as we can. one U-M and one meet and assist		
18:03:08 CAM-8	uh hum.		
18:03:09 CAM-1	alright thanks.		
18:03:10 CAM-7	alright you guys need any drinks or water? all set?		
18:03:12 CAM-1	all fed and watered.		
18:03:13 CAM-2	I'm good.		
18:03:14 CAM-8	how fast today?		
18:03:16 CAM-1	one hour and fifty eight minutes.		
18:03:18 CAM-8	alright.		
18:03:18 CAM-1	see ya.		

18:03:19 CAM-?	lock you guys up?		
18:03:20 CAM-1	yup.		
18:03:21 CAM-8	alright.		
18:03:21 CAM-1	thanks.		
18:03:23 CAM-2	see how many guests there's fifty here and forty nine here. how does that sound?		
18:03:27 CAM-1	perfect.		
18:03:28 CAM-1	* tell you what - I'm gunna - disregard *		
18:03:31 CAM-2	you ah you want it reduced in ah you want zero fuel weight reduced then or do you care?		
18:03:37 CAM-1	no.		

18:03:38 CAM-1	we'll take the extra sheet.		
18:03:43 CAM-2	this is an extra for two five if we need it.		
18:03:46 CAM-1	alright.		
18:03:52 CAM-2	what?		
		18:03:57 RDO-2	Ramp good evening Continental fourteen zero four alpha forty nine to push we have charlie.
		18:04:03 INT-2	what's up?
		18:04:05 Ramp	Fourteen zero four Denver ramp your push is approved call for a west taxi.
18:04:08 CAM-1	call for west taxi.		
		18:04:09 RDO-2	okay after the push call for a west taxi Continental fourteen zero four.

		18:04:14 INT-1	brakes released your cleared to push tail east.
		18:04:18 INT-7	copy that.
18:04:38 CAM-2	I do like this part of the country I can tell you that.		
18:04:41 HOT-1	yeah.		
18:04:47 CAM-2	my in-laws lived in Aspen that was freakin' awesome.		
18:04:50 HOT-2	huh.		
18:04:55 CAM-1	lined up for runway *.		
		18:04:57 INT-7	okay sir you're cleared to start.
		18:04:59 INT-1	roger.
18:05:02 CAM-1	turn one.		

18:05:22 HOT-2	oil pressure rising.		
18:05:35 CAM-1	* start slidin' on this ice.		
		18:05:43 INT-7	okay sir the push back has been complete set brakes.
		18:05:50 INT-1	brakes are set.
18:05:57 HOT-2	start valve closed.		
18:05:58 CAM-1	two please.		
		18:06:11 INT-7	okay sir the tow bar and by-pass pin have been disconnected.
		18:06:15 INT-1	roger stand-by.
18:06:18 HOT-2	oil pressure rising.		

		18:06:32 INT-1	looks like we've got two good starts you're cleared off the headset thanks for the great push see you out front with the pin.
		18:06:37 INT-7	roger that you have a good day.
18:06:46 HOT-2	start valve closed.		
18:06:58 CAM-1	I'm waitin’ for this thing to start slidin'.		
18:07:02 HOT-2	I ah you gotta love winter.		
18:07:04 CAM-1	after start checklist switches closed.		
18:07:31 HOT-2	watch your knees.		
18:07:38 HOT-2	after start checklist generators?		
18:07:40 CAM-1	on.		

18:07:41 HOT-2	pitot heat?		
18:07:42 CAM-1	ah on.		
18:07:43 HOT-2	anti-ice.		
18:07:44 CAM-1	it's on.		
18:07:44 HOT-2	recall.		
18:07:45 CAM-1	is checked.		
18:07:47 HOT-2	auto-brake.		
18:07:48 CAM-1	is RTO.		
18:07:48 HOT-2	flaps.		
18:07:48 CAM-1	set five.		

18:07:50 HOT-2	controls.		
18:07:50 CAM-1	checked.		
18:07:51 HOT-2	flight deck door?		
18:07:53 HOT-2	after start checklist complete.		
18:07:54 HOT-2	he said call ground now for taxi right?		
18:07:56 HOT-1	nope		
18:07:57 HOT-2	no okay		
18:07:57 HOT-1	no ah talk to him		
		18:07:58 RDO-2	Ramp ah Continental fourteen zero four ready to taxi

		18:08:02 Ramp	fourteen zero four you'll follow a nineteen hundred just off your right wing tip to three whiskey ground there twenty seven point five when number one have a good flight
		18:08:09 RDO-2	okay three whiskey and ah twenty seven five when number one there continental fourteen zero four we see that nineteen hundred
18:08:16 HOT-2	okay there he goes clear right		
18:08:20 CAM-2	could that be right		
18:08:21 CAM-1	ah nope		
18:08:23 CAM-1	three whiskey is on the other side of this frontier guy so here's the little nineteen hundred		
18:08:36 CAM-1	three whiskey is the south one		
18:08:37 CAM-2	okay		
18:09:02 HOT-1	follow him		

18:09:08 HOT-2	you done with the ah APU?		
18:09:09 HOT-1	yeah we're all done with that		
18:09:44 HOT-2	grounds up on one		
18:09:47 HOT-1	on one		
18:10:14 HOT-2	kind of up up ahead yet still isn't it three whiskey?		
18:10:17 CAM-1	you you can call her		
18:10:18 CAM-2	okay		
		18:10:38 RDO-2	Denver ground good evening Continental fourteen zero four at three whiskey we have charlie
		18:10:48 GND	Continental fourteen zero four Denver ground taxi to runway three four right via foxtrot

		18:10:55 RDO-2	three four right via foxtrot Continental fourteen zero four
18:10:59 CAM-1	foxtrot that is the second		
18:11:04 HOT-2	second one		
18:11:04 HOT-1	taxi way		
18:11:15 CAM-1	hotel - golf- foxtrot		
18:11:24 CAM-1	alright go where ever the signs say to go		
18:11:46 HOT-1	let me see here so this is ah - he's on foxtrot right?		
18:11:48 CAM-2	that's correct yup		
		18:12:18 GND	Continental fourteen zero four monitor tower one three five point three good night
		18:12:21 RDO-2	talk to tower Continental fourteen zero four good night

18:12:28 CAM-1	do we have a departure freq in our ah ?		
18:12:30 CAM-2	twenty eight twenty five		
18:12:33 CAM-2	as per the SID		
18:12:35 HOT-1	there you go		
18:12:51 HOT-1	** these little RJ guys		
18:12:57 HOT-1	boy that guy Captain sittin' in first class looks like a little scowling		
18:13:03 HOT-1	what are you scowling about dude you've feekin' gutta		
18:13:05 HOT-2	was he scowling?		
18:13:06 HOT-1	I don't know if he was scowling he just looked like he was scowling		

18:13:09 HOT-2	ah		
18:13:10 HOT-1	what do you think he was scowlin' about?		
18:13:12 HOT-2	I don't know		
18:13:15 HOT-2	he had a limp he was all		
18:13:18 HOT-1	he was limping?		
18:13:18 HOT-2	yeah hobblin' around pretty good		
18:13:23 HOT-1	that's what he's got sore leg		
18:13:33 HOT-2	yeah how about this guard's on two ho ho ho		
18:13:37 HOT-1	you wait for that guard to cut you out right when you need to really hear something on your departure		

18:13:45 HOT-1	I like guard you know what the tower can hear guard down here so if somebody's gunna talk on guard I tell ya and maybe guard en-route you know cause anything around the approach control area approach is gunna hear it		
18:13:56 HOT-2	ah huh		
18:13:59 HOT-1	all it does is get in peoples way when it comes to the terminal area that's my opinion anyway		
18:14:07 HOT-1	alright before takeoff checklist		
18:14:08 CAM-2	thirty five three right?		
18:14:14 CAM-2	want the ice protection on for takeoff?		
18:14:16 CAM-1	no let's kill it		
18:14:19 CAM-1	watch your eyes		
18:14:24 CAM-2	the old ones they won't work that well		

		18:14:27 TWR	Continental fourteen zero four Denver tower runway three four right position and hold
		18:14:31 RDO-2	position and hold on three four right Continental fourteen zero four
18:14:34 PA-2	flight attendants please be seated for departure		
18:14:37 CAM-1	position and hold		
18:14:40 CAM-1	lights work		
18:14:43 CAM-2	before takeoff recall check departure briefing complete departure announcement complete air conditioning and pressurization's is set start switches are continuous auto throttles on flaps five set green light ?		
18:14:51 CAM-1	flips five set green light		
18:14:52 CAM-2	takeoff config switch checked		

18:14:54 CAM-1	checked		
18:14:54 CAM-2	transponder TA/RA before takeoff checklist is complete		
18:14:59 HOT-1	clear left		
18:15:15 HOT-1	forgettin' how short these airplanes turn		
18:15:20 HOT-2	it's about as good as it gets ah right there huh		
18:15:22 HOT-1	ah		
18:15:24 HOT-1	*		
18:15:40 CAM	(sound of two clicks)		
18:15:58 CAM-2	did you want three forty four in there?		
		18:16:16 ?	[what are the winds?]

18:16:47 HOT-1	looks like you got some wind out here		
18:16:48 HOT-2	yeah		
18:16:49 HOT-1	**		
18:16:57 HOT-1	oh yeah look at those clouds moving		
		18:17:26 TWR	Continental fourteen zero four wind two seven zero at two seven turn right heading zero two zero runway three four right cleared for takeoff
		18:17:34 RDO-2	heading zero two zero cleared for takeoff runway three four right Continental fourteen zero four
18:17:37 CAM-1	alright		
18:17:38 CAM-1	left cross wind twenty ah seven knots		
18:17:44 HOT-2	huh		

18:17:45 HOT-1	alright look for ninety point nine		
18:17:49 CAM	((sound of increasing engine noise))		
18:17:52 CAM-?	throttles (comin') back		
18:17:54 CAM-?	huh		
18:18:00 HOT-1	check power		
18:18:04 HOT-2	power's set ninety point nine percent		
18:18:13 CAM-?	Jesus		
18:18:14 CAM	sound of snap		
18:18:15 CAM	sound of snap		
18:18:15 HOT-2	oh # # #		

18:18:17 CAM	sound of increasing background noise		
18:18:21 HOT-1	reject		
18:18:22 HOT-1	reject		
18:18:22 HOT-2	*ject		
18:18:27	end of recording / end of transcript		