National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: July 29, 2010
In reply refer to: A-10-105 through -118

The Honorable J. Randolph Babbitt
Administrator
Federal Aviation Administration
Washington, D.C. 20591

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* (CFR) 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 (NTSB) determined 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.[1]

Background

When the DEN air traffic control tower (ATCT) local controller cleared the accident flight for takeoff (at 1817:26), he indicated wind from 270° at 27 knots, which resulted in a 26.6-knot crosswind for runway 34R. This wind was significantly stronger than the wind

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[1] For more information, see *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,* Aircraft Accident Report NTSB/AAR-10/04 (Washington, DC: National Transportation Safety Board, 2010), which will be available on the NTSB's website at <http://www.ntsb.gov/publictn/2010/AAR1004.pdf>.

reported by airport terminal information service (ATIS) (280° at 11 knots) 20 minutes earlier, but it was still within Continental's crosswind guidelines of 33 knots.[2] The pilots initiated the takeoff, which progressed normally at first. However, as the airplane accelerated along the runway centerline, the captain made and relaxed two significant right rudder inputs in an attempt to compensate for a strong and gusty left crosswind that was acting on the airplane. About 1818:13, as the captain was relaxing the second large right rudder input, the nose of the airplane began to move left very rapidly. The airplane 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 investigation revealed that the wind conditions at DEN were more complex and variable than the pilots realized. A study conducted by the National Center for Atmospheric Research (NCAR) during this investigation revealed that significant 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. The NTSB's airplane performance study also indicated that strong, variable crosswinds with gusts to 45 knots were acting on the airplane during the takeoff roll.

Weather Information

Mountain Wave Activity and Associated Local Winds

According to Federal Aviation Administration (FAA) Advisory Circular (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. 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,[3] the NTSB issued two safety recommendations (A-92-57 and -58) asking the FAA to conduct meteorological research and analyze the 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 National Oceanic and Atmospheric Administration and NCAR, conducted research and collected data on hazardous mountain winds and published AC 00-57 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."

The FAA's research satisfied the intent of the earlier safety recommendations; however, that research focused mainly on the effects of mountain wave conditions on airplanes in flight

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[2] 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.

[3] 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).

rather than airplanes on the ground. There is no indication that the results of that research have been applied by air traffic control (ATC) personnel 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 that result from the mountain wave phenomena is the information already recorded by an airport's Low-Level Windshear Alert System (LLWAS).[4] 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 these data available for additional research and the potential future development of an improved LLWAS algorithm for crosswind and gusty wind alerts on ATCT ribbon display terminals (RBDT).

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. The ATIS information, which was recorded about 7 minutes before the pilots began to taxi for takeoff, indicated an 11-knot crosswind, but when the accident airplane reached the departure runway about 10 minutes after that information was recorded, the DEN ATCT local controller provided runway departure end wind information that indicated a 27-knot crosswind.

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 runway 34R was derived from LLWAS sensor #3, which is located

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[4] DEN is equipped with one of the most advanced LLWAS systems in the country, which is designed to continuously collect and analyze wind data collected by 32 remote sensor stations located on and around the airport.

near the departure end of that runway. In the 2 minutes before the DEN ATCT local controller cleared the accident flight for takeoff, the RBDT displayed runway 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 time. When the local controller cleared the accident pilots for takeoff, he reported winds from 270° at 27 knots.

Arrival wind information for runway 34R, which was also displayed on the DEN ATCT local controller's RBDT, 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. The pilots were not given this information.

When the accident flight was cleared for takeoff, runway 34R approach threshold wind information indicated wind from the west at 34 knots. Further, the airport wind (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.[5] However, controllers did not transmit the AW information to the departing pilots and were not required to do so. There was no requirement for ATC personnel to provide wind information from other available sources (such as the AW or information reported by other LLWAS sensors on the airport), nor were there established criteria for controllers to follow in providing alternate 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 threshold wind information with their takeoff clearance, he did not (and he was not 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 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 and 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

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

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.

Use of Runway 34R for Departure

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, the pilots had obtained the departure ATIS winds (from the west at 11 knots), and the minimal resultant crosswind component on runway 34R would not have prompted the pilots to question the safety of a departure on that runway.

The pilots' comments ("Looks like…some wind out there" and "Oh yeah look at those clouds moving") showed that they were aware of the high winds as they approached runway 34R. During postaccident interviews, the accident pilots reported that they were surprised that the updated wind speed issued with their takeoff clearance was so much higher than the 11-knot winds reported by the departure ATIS. However, based on the winds issued by the DEN ATCT local controller (270° at 27 knots), 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. 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.

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.

ATC Assignment of Runway 34R

According to DEN ATCT and terminal radar approach control 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 National Airspace System (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.

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 ATCT did not have a formal runway-use program; however, according to DEN ATC management personnel, they had an unofficial runway-selection policy, which was to 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.[6] Requests for alternate departure runways were rare at DEN and mostly occurred when crosswinds exceeded 30 knots. On the night of the accident, DEN ATCT was operating 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.

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 AW 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. 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

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[6] Although DEN's unofficial 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.

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.

Crosswind Training and Guidelines

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 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.

During postaccident activities, investigators described attempted simulator takeoffs in direct 35-knot crosswinds as only slightly difficult,[7] but 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,

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[7] 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.

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.[8] Pilots given the opportunity to practice takeoffs in realistic strong and gusty crosswind conditions would have a chance to identify effective and ineffective 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.

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

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[8] 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.

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.

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 company guidelines, 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 as asked for in Safety Recommendation A-10-112 has been developed, the FAA require manufacturers of transport-category airplanes to develop type-specific, maximum-crosswind takeoff limitations that account for wind gusts.

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.

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.[9] 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

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

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.

Other Issues

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[10] 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 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, 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.

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,[11] 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

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[10] One G is equivalent to the acceleration caused by the Earth's gravity (32.174 feet per second squared).

[11] 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).

other airplane seats are designed. 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.

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 October 7, 2008.[12] 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.

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.)

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[12] 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.

Records indicated that the galley and its components had satisfied static load requirements during testing conducted by the original manufacturer in 1993.[13] 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 Service Bulletin (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, but 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 recommends that the FAA 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.

Therefore, 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 these 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)

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

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)

In response to the recommendations in this letter, please refer to Safety Recommendations A-10-105 through -118. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our secure mailbox procedures. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

Chairman HERSMAN, Vice Chairman HART, and Members SUMWALT, ROSEKIND, and WEENER concurred with these recommendations.

[Original Signed]

By: Deborah A.P. Hersman
Chairman