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U.S. Report: No Conclusive Evidence Found To Explain Boeing 737 Crash

A routine approach in gusting wind conditions ended suddenly on final to a Colorado airport. An exhaustive U.S. National Transportation Safety Board investigation pointed to several possible factors but failed to determine a conclusive cause for the accident.

Editorial Staff Report

Seconds after turning onto the final approach course for runway 35 at Colorado Springs Municipal Airport, Colorado, U.S., the Boeing 737 rolled abruptly to the right, pitched nose down and struck the ground in a near-vertical attitude.

Following an exhaustive investigation, the U.S. National Transportation Safety Board (NTSB) said it "could not identify conclusive evidence to explain the loss of United Airlines flight 585." The crash killed all 25 people on board, including two flight crew members and three flight attendants.

While the NTSB noted the lack of conclusive evidence to explain the March 3, 1991, accident, it suggested that there were two events that would most likely cause such a sudden, uncontrollable lateral upset — a malfunction of the "aircraft's lateral or directional control system or an encounter with an unusually severe atmospheric disturbance." Both engines were operating and developing power at the time of impact and the crew did not report any malfunctions or difficulties," the report said.

The NTSB report concluded: "Although anomalies were identified in the airplane's rudder control system, none would have produced a rudder movement that could not have been countered by the airplane's lateral controls. The most likely atmospheric disturbance to produce an uncontrollable rolling moment was a rotor (a horizontal-axis vortex) produced by a combination of high winds aloft and the mountainous terrain.

"Conditions were conducive to the formation of a rotor, and some witness observations support the existence of a rotor at or near the time and place of the accident. However, too little is known about the characteristics of such rotors to conclude decisively whether they were a factor in this accident."

But the NTSB said it considered "the presence of a severe rotor more likely, although the Safety Board cannot explain the absence of certain expected events, such as pressure changes that should be apparent on an indicated altitude readout of the FDR."

Flight 585 originated in Peoria, Illinois, with stops in Moline, Illinois, and Denver, Colorado, before its scheduled final destination in Colorado Springs.

In Denver, a scheduled crew change was made and the aircraft, being flown by the accident crew, departed Denver at 0923 for an estimated arrival at Colorado Springs of 0942. The accident occurred at 0943:41.

The accident crew began their trip on March 2, departing from Oakland, California, with landings in Los Angeles and Sacramento, California, and an 1828 landing in Denver. Another pilot said that the crew appeared alert and well rested when they arrived for the accident flight the next morning.

"During the accident flight, he [the captain] commented to the first officer that he had 'never driven to Colorado Springs and not gotten sick' … ."

The cockpit voice recorder (CVR) indicated that the crew received automated terminal information service (ATIS) information "Lima" at 0930 that was about 40 minutes old. It reported the wind at 310 degrees at 13 knots with gusts to 35 knots. It also said that low-level wind shear advisories were in effect with a "local aviation wind warning in effect calling for winds out of the northwest, gusts to 40 knots and above."

According to the CVR and the flight data recorder, the flight crew "added 20 knots to the approach landing reference target airspeed based on the ATIS information."

The Colorado Springs controller cleared the aircraft to land and reported winds at 320 degrees at 16 knots with gusts to 29 knots. A few moments later, the first officer asked the controller if other aircraft had reported significant airspeed losses or gains on final. "The controller replied that a Boeing 737 [had] reported a 15-knot loss at 500 feet [151 meters], at 400 feet [121 meters] 'plus 15 knots,' and at 150 feet [45 meters], 'plus 20 knots.' The first officer replied, 'sounds adventurous, uh, United 585, thank you.'"

About 20 seconds prior to the crash, the rate of heading change increased, consistent with a 20-degree bank angle and a turn for alignment with the runway, the NTSB said.

"Sixteen seconds prior to the crash, the thrust was increased to about 6,000 pounds per engine. As the thrust was increasing, the first officer made the '1,000 feet' [303 meters] call. Within the next four seconds, and about nine seconds prior to the crash, the heading rate increased to about five degrees per second to the right, nearly twice that of astandard rate turn. The first officer said 'Oh God,' followed by the captain, in the last eight seconds, calling for 15 degrees of flaps. This selection of 15 degrees of flaps, in combination with increased thrust, is consistent with the initiation of a go-around. The altitude decreased rapidly, the indicated airspeed increased to over 200 knots, and normal acceleration increased to over 4 G[s]."

The captain, 52, was hired by United Airlines in 1969. He had logged a total of 9,902 flying hours, of which 1,732 were in the Boeing 737-200. The NTSB said the landing was the captain's first at Colorado Springs as pilot-in-command, but added that it was likely that the captain had landed there many times as a flight crew member. "During the accident flight, he [the captain] commented to the first officer that he had 'never driven to Colorado Springs and not gotten sick,' signifying that this was probably not his first landing or first experience with turbulence on the segment to Colorado Springs," the NTSB said.

The first officer, 42, was hired by United in 1988. She had logged a total of 3,903 flying hours, including 1,077 hours as first officer in the Boeing 737. It was her second landing approach to Colorado Springs.

The accident aircraft was manufactured in 1982. By the accident date, the aircraft had accumulated 26,050 hours and 19,734 cycles.

The wreckage site was about 3.47 nautical miles (6 kilometers) south of the south end of runway 35. "Measurements of the wing tip debris, the engine shafts and the tree strikes indicated an impact heading of 205 degrees, an 80-degree nose-low attitude, a four degree nose-right yaw and a right rolling motion," the NTSB said.

The NTSB said that "except for two aft fuselage sections of skin and small debris, the entire fuselage was contained within the impact crater."

Wreckage examinations of the fuselage found no evidence of pre-impact failures or malfunctions, the report said.

"An intense ground fire melted localized sections of the airplane structure and scorched nearby trees and the ground surrounding the crash site," the NTSB said. "There was no indication of any fire prior to the impact with the ground."

Extensive flight and weather-simulation tests were conducted in an effort to replicate conditions at the time of the crash and to determine if flight control system anomalies contributed to the accident, the NTSB said.

"Analysis of air traffic control (ATC) and flight data recorder (FDR) data show that the airplane intercepted the glideslope at 0942:50 and started a normal descent," the NTSB said. "However, about 10 seconds later, a deviation from steady flight began, just before the weak 'wow' comment was recorded on the CVR. The airplane descended below the glideslope for the next 30 seconds until lateral control was lost. At the time lateral control was lost, the airplane was about 400 feet [121 meters] below the glideslope. Evidence from the CVR indicated that the pilots were caught by surprise by a rapidly developing event during which control of the airplane was lost." (Figure 1)

The NTSB said it assumed that the crew "responded rapidly with control wheel rotation to counteract the roll of the airplane."

To determine what caused the loss of control, the NTSB considered the following scenarios:

- Loss of directional control (uncommanded rudder deflection);

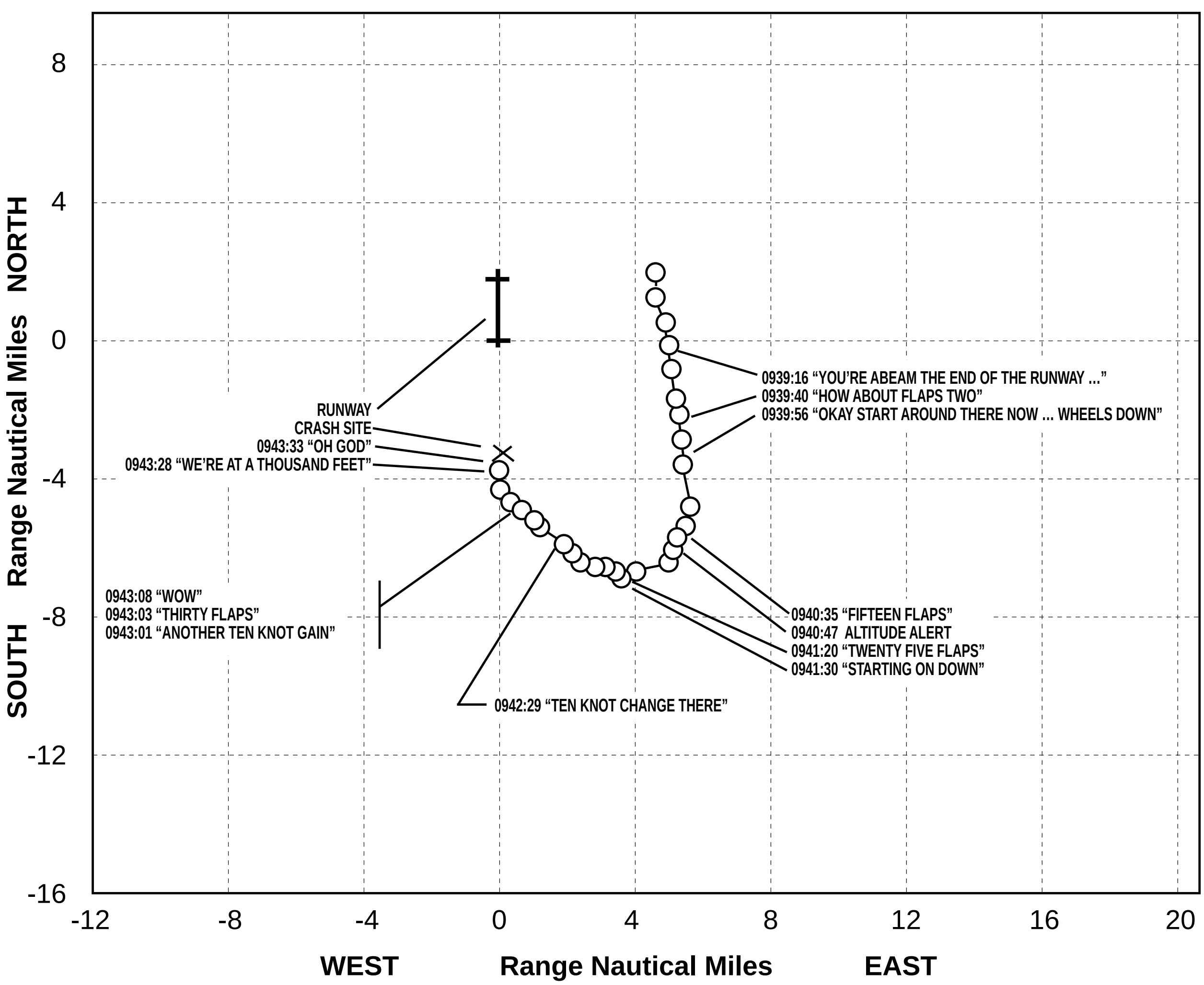
- Loss of lateral control (failure of the lateral systems — flaps, slats, spoilers and ailerons);

- Atmospheric conditions (wind shears and rotors); and,

- A combination of airplane malfunctions, atmospheric disturbances, structural failures, engine failures or flight crew performance.

The NTSB said that some witnesses reported hearing "popping or cracking sounds" coming from the airplane

Flight 585 Ground Track Based on Radar Data



Source: *U.S. National Transportation Safety Board*

Figure 1

when it was about one-half mile from the crash site.

"Witnesses also reported observing a 'mist' trailing the airplane's right wing. Both the sounds and the mist could have been associated with engine surges (compressor stalls) that could have accompanied an attempted relight and acceleration of engines in the presence of turbulent air."

But the NTSB report added: "Engine thrust variations alone, even with a total flameout, cannot explain the loss of lateral control."

The post-crash investigation also found no evidence of a structural failure that would have allowed fuel or hydraulic fluid to escape and there was no evidence of control system failures. "Simulations showed that various potential mechanical failures [tested] failed to produce significant control difficulties."

Most of the weather investigation focused on the possibility that a rotor caused the accident, the NTSB said. But the report also said another phenomenon known as a "jump" (a concentrated region of upward vertical motion) was also considered.

The report said that the U.S. National Oceanic and Atmospheric Administration (NOAA) confirmed that rotors can occur in the accident area and "can be quite strong." Clouds are not always associated with rotors, and thus rotors can be invisible until encountered, the NTSB said.

The NTSB compiled all relevant pilot reports on the day of the accident and interviewed area witnesses who might have knowledge about rotors in the area.

An airline pilot who had flown in the area for more than 25 years reported that "during strong mountain wave conditions, rotors have occurred over the approach to runway 35."

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Another witness, also a pilot, said he observed a rotor hit the ground about 1/2 mile (0.8 kilometers) east and five miles (8 kilometers) north of the extended centerline of runway 35 with estimated wind speeds of up to 80 mph (129 kph) at about noon on the day of the accident.

The report said, "Tree limbs were blown off and car hoods were damaged. He [the pilot witness] believed that the rotor was part of a line of rotors extending north to south which would most likely have extended to the area where the accident occurred. He added that the force of rotors impacting the ground has severely damaged houses, railroad cars and trucks. Calm returned after 30 seconds."

The NTSB said one witness reported a brief 90 mph (145 kph) or stronger gust from the west about two miles (3 kilometers) east (downwind of the accident site) and another witness reported a 50- to 70-knot gust about 1.25 miles (2 kilometers) east of the accident site. But it added that "most witnesses near the accident site reported light winds."

In addition, pilot reports on the day after the crash indicated that flights encountered measured turbulence and vertical velocities of 800 feet (242 meters) to 1,000 feet (303 meters) per minute in the area of the accident. Atmospheric conditions were similar to those on the day of the accident.

"A [Beechcraft] Super King Air pilot ran into 'terrible shear' in the area of the crash," the report said. "At 7,500 feet [2,273 meters] AGL (above ground level) the airplane lost 20 knots of airspeed and 100 feet [30 meters] of altitude. He described it as a very hard hit."

The NTSB report also considered scenarios in which a combination of "individual, non-critical events led to the crash."

The report said, "The meteorological conditions had the potential to produce control difficulties, and the rudder MPCU (main power control unit) had two design features that could have resulted in loss of control or effectiveness of the rudder. Further, the standby rudder actuator and yaw damper had anomalies that could have caused minor control difficulties. Lastly, it is possible that some undetermined flight crew action or inaction could have contributed to the loss of control."

First evidence of a potential rudder control problem on the aircraft occurred six days before the accident flight, when the flight crew experienced a transient, uncommanded yaw to the right. The crew turned off the yaw damper and no further uncommanded yaws were experienced during the flight. Following the flight, maintenance personnel replaced the yaw damp coupler.

Two days later, another crew experienced an uncommanded yaw to the right, and they also turned off the yaw damper, which appeared to correct the problem. Maintenance personnel subsequently replaced the yaw damper transfer valve in the rudder MPCU.

The NTSB said that while the maintenance operations were conducted in accordance with normal practices, it was doubtful that the actions corrected the problem as both removed components were later shown to operate normally.

"During the postcrash investigation of the MPCU," said the report, "it was found that one of the electrical wires to the solenoid was loose and circuit continuity was intermittent ... and could have been the cause of the uncommanded yaws. If this were the case, the effect of the discrepancy would be erratic deflections of the rudder when the yaw damper was in use. However, by design, the authority of the yaw damper is limited to two degrees of rudder travel. While uncommanded rudder movements of two degrees or less could produce noticeable side loads, they would have little or no effect on controllability."

However, the NTSB said it believed that the "binding of the input shaft to the bearing that is threaded in the standby rudder actuator body could also have produced the two transient uncommanded yaws experienced during previous flights."

["A rudder movement initiated by the yaw damper will produce a small angular movement of the standby rudder actuator input crank," the report said. "If the crank is not free to move relative to the actuator body, the feedback loop to the MPCU servo valve will be affected so that a rudder deflection command signal may be applied to the MPCU through rotation of the torque tube. The rudder could then move beyond normal yaw damper limits … the resultant deflection could be as much as 5.5 degrees. Simulation tests showed that this rudder movement could easily be countered by the airplane's lateral controls. Although the airplane would be in a sideslip with some resultant performance penalties, a loss of control is unlikely."]

The report said a teardown examination of the airplane's hydraulic components showed "considerable evidence

Cockpit Voice Recording of United Flight 585's Final Moments

0941:30	Captain: *Starting on down.*
0941:51	Sound similar to that of stabilizer trim actuation.
0942:08	First Officer: *The marker's identified now, it's really weak.*
0942:11	Captain: *No problem.*
0942:29	First Officer: *We had a 10-knot change there.*
0942:31	Captain: *Yeah, I know ... awful lot of power to hold that … airspeed.*
0942:38	First Officer: *Runway is ah 11,000 feet long.*
0942:42	Captain: *Okay.*
0943:01	First Officer: *Another 10-knot gain.*
0943:03	Captain: *Thirty flaps.*
0943:05	Sound similar to that of flap level actuation.
0943:08	First Officer: *Wow.*
0943:09	Sound similar to that of an engine power reduction.
0943:28.2	First Officer: *We're at a thousand feet.*
0943:32.6	First Officer: *Oh God.*
0943:33.5	Captain: *Fifteen flaps.*
0943:34.0	First Officer: *Fifteen.*
0943:34.4	First Officer: *Oh.*
0943:34.7	Captain: *Oh* [exclaimed loudly].
0943:35.4	First Officer: [expletive].
0943:35.5	Click sound similar to that of a flap lever actuation.
0943:35.7	Captain: [expletive].
0943:36.1	Click sound similar to that of a flap lever actuation.
0943:36.5	Captain: *No* [very loud].
0943:37.4	Click sound similar to that of a flap lever actuation.
0943:37.5	First Officer: *Oh* [expletive].
0943:38.2	Captain: *Oh* [expletive].
0943:38.4	First Officer: *Oh my God* [unidentifiable click sound] ... *oh my God* ... [a scream].
0943:40.5	Captain: *Oh no* [expletive, exclaimed loudly].
0943:41.5	Sound of impact.

Source: *U.S. National Transportation Safety Board* of contamination in the A, B and standby systems." It said most of the contaminants were parts of O-rings or backup rings that had migrated through the system but that they would have had no effect on essential flight control components.

Referring to a scenario in which a combination of events caused the crash, the report added: "As the airplane was turning from the 45-degree intercept angle to final approach, aligned with the runway, it is possible that atmospheric disturbances rapidly rolled the airplane wings level against pilot control inputs to continue the right bank.

"If the pilot applied additional control forces to continue the bank to the right at the same time that the airplane reached a position at which the rolling moment caused by an atmospheric disturbance reversed, an excessive right roll and subsequent loss of control could have been precipitated."

The NTSB said that while it could not entirely discount the possibility of a partial loss of rudder response, simulator data indicated that the lack of rudder response lowered only by a small amount the rotor severity required for an upset.

"Regardless of the availability of rudder motion, a severe rotor 10 times worse than those previously documented would have had to be present to cause the upset," the NTSB said. "A less severe rotor motion, combined with pilot delay in reaction, could have led to the upset. However, the CVR data revealed a rapid verbal, and presumably physical, response to the upset by the pilots."

The report also acknowledged the possibility that some part of the flight control system malfunctioned, but went undetected during the investigation. But the NTSB said it believed that the likelihood of a loss of rudder response caused by rudder system anomalies, which were identified in the investigation, was low.

"Either meteorological phenomena or an undetected mechanical malfunction or a combination of both could have led to the loss of control," the NTSB said.

Following the investigation, the NTSB recommended that The Boeing Co. develop a maintenance test procedure for 737 operators to verify the proper operation of the rudder MPCU servo value until a design change is implemented.

The NTSB also recommended that the U.S. Federal Aviation Administration (FAA) develop a meteorological program to study potential meteorological aircraft hazards in the Colorado Springs area, with a focus on approach and departure paths. It also urged a broader program be implemented to include other airports in or near mountainous terrain. ♦

This article was adapted from NTSB report # AAR-92/06, United Airlines Flight 585 Boeing 737-291, N99UA Uncontrolled Collision with Terrain for Undetermined Reasons 4 Miles South of Colorado Springs Municipal Airport, Colorado Springs, Colorado. *It can be obtained from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161, U.S. Telephone: (703) 487-4600.*

ACCIDENT PREVENTION
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Staff: Roger Rozelle, director of publications; Girard Steichen, assistant director of publications; Kate Achelpohl, editorial assistant; and Ashton Alvis, production coordinator

Subscriptions: US$70 (U.S.-Canada-Mexico), US$75 Air Mail (all other countries), twelve issues yearly. • Include old and new addresses when requesting address change. • Flight Safety Foundation, 2200 Wilson Boulevard, Suite 500, Arlington, VA 22201-3306 U.S. • telephone: (703) 522-8300 • telex: 901176 FSF INC AGTN • fax: (703) 525-6047