



National Transportation Safety Board Aviation Accident Final Report

Location:	Conroe, TX	Accident Number:	CEN14FA505
Date & Time:	09/19/2014, 0847 CDT	Registration:	N322QS
Aircraft:	EMBRAER EMB 505	Aircraft Damage:	Substantial
Defining Event:	Runway excursion	Injuries:	2 None
Flight Conducted Under:	Part 91: General Aviation - Positioning		

Analysis

The pilot-in-command (PIC) and second-in-command (SIC) were conducting a positioning flight. According to the dispatch flight release, the pilots planned to land on runway 14, which was assumed to be wet. Before the flight, notices to airmen (NOTAMs) had been issued, which stated that the runway 14 threshold had been displaced 3,377 ft and that the instrument landing system and RNAV instrument approaches were not available. Although the NOTAMs were included in the flight release paperwork, dispatch personnel overlooked them, which resulted in flight planning numbers predicated on the full length of runway 14.

During the approach, the pilots listened to the automatic terminal information service information and then became aware that runway 14 was shortened due to construction. Subsequently, the pilots calculated the landing distance required to land on a wet runway and chose to land on runway 1, which was the longer runway. The PIC reported that, during the approach, they encountered light rain but that the rain was moving away from the airport, which alleviated any concern regarding standing water on the runway.

A review of flight data recorder data showed that the SIC flew a stabilized approach 9 knots above the reference speed (V_{ref}) and that the airplane touched down 903 ft from the runway threshold at a groundspeed of 118 knots. The SIC stated that he began braking with half pressure and continued to increase the brake pressure to maximum, which was the normal braking procedure, but that the airplane did not appear to be decelerating. FDR data confirmed that the SIC began applying the brakes immediately upon touchdown and progressively commanded full braking performance from the brake system.

The PIC informed the SIC that they needed to slow down, and the SIC replied that he had "no braking." The SIC then applied the emergency parking brake (EPB), but the airplane still did not slow down. FDR data indicated that the airplane achieved its maximum deceleration during the landing roll before the application of the EPB. FDR data showed that, once the SIC applied the EPB, the wheel speed dropped to 0. After determining that there was insufficient runway remaining for a go-around, the pilots realized that the airplane was going to exit the

end of the runway. Subsequently, the airplane began to skid along the runway, which resulted in reverted-rubber hydroplaning, thus decreasing the stopping performance, and then exited the departure end of the runway and continued about 400 ft in soft terrain before it impacted a ditch and came to a stop.

An examination of the brake system and data downloaded from the brake control unit indicated that the brake system functioned as commanded during the landing. Analysis of the runway surface and the amount of precipitation showed that there should have been no standing water on the runway. Landing distance calculations performed in accordance with the aircraft flight manual (AFM) showed that, even though the SIC exceeded V_{ref} , the airplane should have been able to stop on the available runway.

According to the National Transportation Safety Board's airplane performance study, the maximum wheel braking friction coefficient achieved during the portion of the ground roll before the application of the EPB was significantly less than the maximum wheel braking coefficient that would have been expected given the unfactored wet-runway landing distances published in the AFM. However, the study determined that, if the EPB had not been engaged and airplane had maintained the braking friction level attained during the landing roll before the engagement of the EPB, it would have been able to stop on the available runway. Therefore, the SIC's application of the EPB, which locked the wheels, reduced the friction level, and decreased the braking performance, prevented the airplane from stopping on the available runway.

Nonetheless, the braking friction deficit observed in this accident showed that the stopping performance of the airplane was more consistent with AFM landing distances for runways contaminated with standing water than for runways that were merely "wet" even though it was determined that the runway could not have been flooded.

Since the accident, the operator has issued a flight operations bulletin instructing pilots to conduct a landing distance assessment using the AFM contaminated runway performance data for the lowest contamination depth when the following three conditions exist: 1) the runway did not have a treated surface, 2) thrust reversers were deferred or not installed, and 3) the airport was reporting rain or heavy rain.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be: The second-in-command's (SIC) engagement of the emergency parking brake (EPB), which decreased the airplane's braking performance and prevented it from stopping on the available runway. Contributing to the SIC's decision to engage the EPB was the lower-than-anticipated deceleration due to a wet-runway friction level that was far lower than the levels used to determine the wet-runway stopping distances in the Airplane Flight Manual (AFM) and necessitated a landing distance considerably greater than that published in the AFM.

Findings

Aircraft	Surface speed/braking - Not specified (Cause) Surface speed/braking - Not attained/maintained (Factor)
Personnel issues	Use of equip/system - Copilot (Cause) Decision making/judgment - Copilot (Factor)
Organizational issues	Equip certification/testing - Manufacturer (Cause) Document/info verification - Manufacturer (Factor)

Factual Information

HISTORY OF FLIGHT

On September 19, 2014, about 0847 central daylight time, an Embraer EMB-505 Phenom 300 airplane, N322QS, impacted a ditch after the airplane departed the end of the runway while landing at Lone Star Executive Airport (CXO), Conroe, Texas. Neither of the two airline transport-rated pilots were injured. The airplane was substantially damaged. The airplane was being operated by NetJets Aviation, Inc. (NetJets), as a 14 Code of Federal Regulations (CFR) Part 91 positioning flight. Instrument meteorological conditions existed at the airport at the time of the accident, and an instrument flight rules flight plan had been filed. The flight originated from Nashville International Airport, Nashville, Tennessee, at 0706.

According to the dispatch flight release paperwork, the pilot-in-command (PIC) and second-in-command (SIC) planned to land on runway 14, which was assumed to be wet. Before the flight, notices to airmen (NOTAMs) had been issued, which stated that the runway 14 threshold had been displaced 3,377 ft and that the instrument landing system (ILS) and RNAV instrument approaches were not available. Although the NOTAMs were included in the flight release paperwork, dispatch personnel overlooked them, which resulted in flight planning numbers predicated on the full length of runway 14.

According to cockpit voice recorder (CVR) information, at 0827:04, the pilots received the automatic terminal information service (ATIS) information, which indicated that the runway 14 takeoff and landing distance was 4,111 ft and that the ILS for runway 14 was out of service. The pilots calculated the runway length required for a wet runway landing and then chose to land on runway 1, which was the longer runway. The PIC stated that, during the approach, the flight encountered light rain but that the rain was moving from the northwest to the southeast, away from the airport and that this alleviated any concern about standing water on the runway. He added that both he and the SIC had previously landed the EMB-505 in moderate-to-heavy rain with no decrease in braking ability.

The CVR recorded the pilots briefing the approach and missed approach procedures. Subsequently, the tower controller cleared the runway 1 RNAV approach, and the pilots then discussed alternate airports in the area. At 0841:30, the tower controller cleared the airplane to land and stated that moderate-to-heavy rain was at the airport. The pilots conducted the Before Landing checklist and continued the approach. While continuing the approach with the SIC flying the airplane, they saw the runway at 600 ft above ground level, and the copilot disengaged the autopilot at 400 ft. At 200 ft, the SIC reduced the power and adjusted the altitude and airspeed for a stabilized approach with a maximum airspeed during the approach of 130 knots.

In his postaccident written statement, the PIC stated that the landing appeared normal and "smooth." The SIC stated that he began braking with half pressure and continued to increase the brake pressure to maximum, which was the normal braking procedure. Sounds recorded on the CVR consistent with the airplane touching down were heard at 0837:13, followed by the pilots stating that the airplane was not slowing down. The SIC stated, "brakes. Emergency brakes," followed by "nothin' man" and "I got nothin'." The PIC stated "where's the brakes,"

followed by "where are they?" The PIC then said "go...don't go sideways, don't go sideways." The airplane exited the departure end of the runway and continued about 400 ft through soft/muddy terrain before coming to rest half-way down a ditch.

According to the air traffic controller who witnessed the accident, the pilots flew the RNAV runway 1 approach and broke out of the clouds at the minimums for the approach. The controller stated that the airplane touched down just past the 1,000-ft marker on the runway and did not appear to decelerate as it continued down the runway.

PERSONNEL INFORMATION

PIC

The PIC held an airline transport pilot certificate with an airplane multiengine land rating and a commercial pilot certificate with airplane single-engine land and balloon ratings. He held type ratings in Cessna 500, 650, and 750; Embraer 505; and Hawker Siddeley HS-125 airplanes. A limitation on the EMB-505 type rating was the requirement of an SIC. The PIC's last flight check was in the EMB-505 on May 12, 2014. The PIC was issued a first-class Federal Aviation Administration (FAA) medical certificate on April 3, 2014, which contained the limitations that it was not valid for any class after October 31, 2014, and that he must wear corrective lenses. He had 13,466 hours of flight time, of which 322 hours were in EMB-505 airplanes.

SIC

The SIC held an airline transport pilot certificate with an airplane multiengine land rating and a commercial pilot certificate with an airplane single-engine land rating. He held type ratings in ATR-42, ATR-72, Cessna 750, Bombardier CL-65, and Embraer 505 airplanes. Limitations on the CL-65 type rating were SIC privileges only and circling approaches in visual meteorological conditions. A limitation on the EMB-505 type rating was the requirement of an SIC.

The SIC's last flight check was in the EMB-505 on May 12, 2014. The SIC was issued a first-class FAA medical certificate on July 22, 2014, with no limitations. He had 9,861 hours of flight time, of which 361 hours were in EMB-505 airplanes.

AIRCRAFT INFORMATION

The accident airplane was a twin-engine turboprop, low-wing airplane, serial number 50500165, manufactured in 2013. The airplane was type certificated as a 14 CFR Part 23 commuter category airplane and was configured for two flight crewmembers and seven passengers. The airplane was equipped with two Pratt & Whitney PW535E turboprop engines, each of which delivered 3,360 lbs of thrust.

The airplane was maintained in accordance with the manufacturer's inspection program. The last inspection was completed on July 2, 2014, at a total airframe time of 597.7 hours.

Brake System

The airplane's hydraulic brake system delivered hydraulic pressure to the brakes via input from the brake pedals. The hydraulic pressure to the brake system was supplied at a maximum of

3,000 pounds per square inch (psi). The SIC (right seat) brake pedals were mechanically linked to the PIC (left seat) brake pedals. Each PIC brake pedal was connected to a pedal position transducer (PPT), each of which produced two independent electrical outputs that were proportional to the respective pedal displacement to the brake control unit (BCU). The BCU controlled the main brake system, which was a brake-by-wire system with an antiskid function. The only pedal force feedback to the pilots was from a force spring installed on the pedals that provided a consistent pedal resistance regardless of the runway condition and the pressure applied.

Wheel speed information was sent to the BCU via two axle-mounted speed transducers. The BCU factored the output from the wheel speed transducers, the PPTs, and two brake line pressure transducers then sent an electrical command to the associated brake control valve.

The brake system had an antiskid function (which controls slip ratio) and a locked-wheel protection (which detects deep skids). The antiskid function worked independently on each wheel by comparing the current wheel angular speed to a reference angular speed, which was calculated based on the speed of that same wheel. The locked-wheel protection compared both main landing gear (MLG) wheel speeds and alleviated brake pressure when the slower wheel fell below 30% of the opposite wheel speed.

The airplane was equipped with an EPB to stop the airplane if the main brake system failed. The EPB was operated by a T-handle on the control pedestal, which was mechanically linked via a steel cable to the EPB valve. The antiskid function was not available when using the EPB.

An examination of the brake system and the data downloaded from the brake control unit (BCU) indicate that the brake system functioned as commanded during the landing.

Ground Spoiler Function

The airplane had a ground spoiler function that deployed the spoiler panels on the ground during landing to decrease lift, increase drag, improve braking, and reduce stopping distance. The airplane must be on the ground, the thrust levers must be in the "idle" position, and the ground spoilers must be armed for them to deploy during landing. The ground spoiler function automatically armed when the weight-on-wheels (WOW) sensors indicated "in-air" for more than 10 seconds and the airspeed was valid and greater than 60 knots indicated airspeed (KIAS).

Certification

In general, 14 CFR Part 23 certification regulations require that dry-runway landing distances be published in airplane flight manuals (AFM) and that they be based on performance demonstrated during flight tests on smooth, dry, hard-surfaced runways. Certification regulations do not require the publication of landing distances on other-than-dry runways, although certification applicants may choose to present this information to the regulator. If the applicant provided this information, it would not necessarily be based on flight tests (largely because of the difficulty of achieving a consistent "wet" or "contaminated" runway surface) but rather derived by calculations based on assumptions agreed to by the regulator.

The EMB-505 was first certificated by the Brazilian regulator (the Agência Nacional de Aviação Civil), which, like the FAA, does not require the publication of landing distances on other-than-dry runways. However, the European Aviation Safety Agency (EASA) does require the publication of landing distances on other-than-dry runways if the airplane is to be operated on such runways. Therefore, to certify the airplane in Europe, Embraer proposed to EASA that the unfactored wet-runway landing distances presented in the EMB-505 AFM would be computed as 125% of the demonstrated, unfactored dry-landing distance, and EASA accepted this proposal. The unfactored landing distance is the actual distance from the runway threshold required to land the airplane and stop it without any safety factors applied. The factored landing distance is the actual distance from the runway threshold required to land the airplane and stop increased by a safety factor.

The factored wet-runway distances in the EMB-505 AFM were 115% of the factored dry distances, or 192% of the unfactored dry distances. The EMB-505 AFM also provided a table of landing distances for landings on runways covered with standing water, slush, or wet snow at depths of 0.125, 0.250, and 0.375 inches.

METEOROLOGICAL INFORMATION

At 0841, the CXO automated surface observation system reported calm wind, visibility 2 miles in heavy rain and mist, a few clouds at 500 ft above ground level (agl), ceiling 8,000 ft agl broken, 10,000 ft agl overcast, temperature 23° C, dew point 22° C, and altimeter setting of 29.93 inches of Mercury. Remarks included the following: hourly precipitation 0.21 inch, temperature 22.8° C, and dew point 22.2° C.

A review of weather observations reported before and after the accident showed that the rain began at 0444. The rain varied from moderate-to-heavy intensity from 0725 until after the accident. The rain ended at 1129. The total precipitation reported between 0444 and 0847 (the time of the accident) was 0.45 inch. The total precipitation reported between 0444 and 1129 was 0.50 inch.

AIRPORT INFORMATION

CXO is located about 37 miles north of Houston, Texas. The airport is equipped with an air traffic control tower, which is operational between 0700 and 2200. The airport chart supplement lists an elevation of 245 ft and a magnetic variation of 5° east. Runway 1/19 is 5,000 ft long and 100 ft wide, concrete, and in good condition with a threshold elevation of 230 ft and 0.2% grade. The runway has a medium-intensity approach lighting system and nonprecision runway marking. The runway also has a two-light precision approach path indicator lighting system, which was out of service.

Runway 14/32 was under construction at the time of the accident. As noted earlier, a NOTAM had been issued, which stated that the runway 14 threshold had been displaced 3,377 ft and that the ILS and RNAV instrument approaches were not available.

The dispatch Flight Release for N322QS, showed that the landing was planned for runway 14 which was assumed to be wet. The NOTAMs were included in the Flight Release paperwork, but were overlooked by dispatch resulting in flight planning numbers predicated on the full

length of runway 14. The pilots became aware of the runway information during the flight and they opted to land on runway 01.

The automated terminal information service (ATIS) ZULU which was received by the crew reported the runway 14 takeoff and landing distance was 4,111 ft and the ILS for runway 14 was out of service.

WRECKAGE AND IMPACT INFORMATION

According to the FAA inspector who arrived on scene shortly after the accident, there were light tire scuffmarks on runway 1, which began 1,877 ft before the departure end of the runway. There were no visible signs of rubber transfer on the runway. The airplane exited the departure end of the runway and continued about 400 ft through soft/muddy terrain before coming to rest on down-sloping terrain. The distance between the ground tracks made by the nose tire and the right MLG gear track was 18 inches, indicating that the airplane skidded after it departed the runway surface. A flat worn spot was visible on both the left and right main tires. Both tires showed evidence of reverted rubber hydroplaning.

The airplane contacted a silt/erosion control fence during the overrun. The nose landing gear collapsed and separated from the airplane just before it came to rest.

The airplane sustained substantial damage, including, but not limited to, damage to the forward bulkheads, composite ribs, forward fuselage frame, and the center fuselage area.

Power was applied to the airplane after the accident, and a ground hydraulic power stand was used to generate a hydraulic system pressure of 2,850 psi. The brakes and spoiler system were tested, and both functioned normally. The antiskid auto-startup test was completed with no faults noted.

TESTS AND RESEARCH

BCU and Central Maintenance Computer (CMC)

The BCU, serial number 276920254, was removed from the airplane and sent to Meggitt in the United Kingdom. The recorded faults were downloaded, and the BCU was functionally tested under the supervision of an investigator from the Air Accidents Investigation Branch, and it functioned normally.

Embraer downloaded the CMC messages on scene with the concurrence of the National Transportation Safety Board (NTSB) investigator-in-charge. The BCU faults and CMC faults and messages were correlated with one another and reviewed by Embraer. Although the BCU and CMC recorded four sequences of faults and messages, the data and the examination of the brake system indicated that the brake system functioned as commanded during the landing.

FLIGHT RECORDERS

The airplane was equipped with an L-3/Fairchild FA2100-3083 combination cockpit voice and flight data recorder (CVDR), serial number 000885510, which provided both flight data recorder (FDR) and cockpit voice recorder (CVR) functions. The CVDR was removed from the

wreckage and examined at the NTSB Vehicle Recorder Laboratory, Washington, DC. The CVR contained 2 hours 4 minutes 14 seconds of good quality voice recordings. A CVR group was convened, and a transcript was prepared for the period from 0824:47 to 0848:01.

FDR Data

The FDR contained 222 hours of data. Timing of the FDR data is measured in subframe reference numbers (SRN), where each SRN equals 1 lapsed second. The accident flight was the last flight on the recording, and the flight duration was about 1 hour 37 minutes.

The FDR data showed the airplane initially on approach above 150 knots. From 0844:18 to 0844:38, the flap position increased from flap position "one" through to flap position "three," at which position it remained for the rest of the approach. At 0844:43, the brake pressure for the left and right MLG briefly spiked to about 3,000 psi and quickly returned to 0. During this time, the pilot brake pedal position remained near 0. The airplane continued the approach, and its approach speed steadily decreased to about 130 knots while on short final.

At 0847:09, the brake pedal position parameters became active, and they began to increase just before touchdown. One second later, the left and right main wheel spin became active and then increased rapidly. Two seconds later, the speed brakes began to extend, and they reached maximum extension at 0847:14. About the same time, all four WOW discrete parameters became true. Between 0847:14 and 0847:24, the brake pressure for both MLG remained below 1,000 psi. During this time, the pilot left and right brake pedal positions increased to about 36 millimeter (mm) of pedal travel as the indicated airspeed, groundspeed, and wheel speed for both MLG steadily decreased. At 0847:24, the EPB discrete became active. Immediately thereafter, the brake pressure for both MLG plateaued near the system's maximum value of 3,000 psi, and the wheel speed quickly decreased to about 0 knots.

Between 0847:27 and 0847:42, the brake pressure for both MLG remained plateaued about 3,000 psi. The pilot left and right brake pedal positions also remained steady about 35 mm of pedal travel as the KIAS and groundspeed continued to decrease. At 0847:24, a brake fail indicator discrete became active as the brake pressure for both MLGs dropped to 0 psi, and the pilot left and right brake pedal positions remained near the system's maximum pedal travel value while the airplane was experiencing measurable changes in tri-axis acceleration, consistent with it departing the runway surface. KIAS and groundspeed quickly dropped to about 0 knots, and the speed brake surface positions for the left and right speed brakes bleed position decreased to 0. The FDR recording ended at 1347:59 and showed the airplane at rest.

Airplane Performance Study

The NTSB conducted an airplane performance study for the accident flight to determine the airplane's position and orientation during the relevant portion of the flight and its responses to control inputs, external disturbances, ground forces, and other factors that could affect its trajectory.

According to the performance study, the airplane's approach to runway 1 complied with the operator's stabilized approach criteria, with the airplane tracking the RNAV final approach course and glideslope at an airspeed of about 130 knots. The airplane crossed the runway

threshold at 121 knots (9 knots faster than Vref) and 45 ft above the runway and touched down about 903 ft from the threshold at a groundspeed of 118 knots. The headwind component at touchdown was negligible.

After touchdown, the pilot brake pedal deflections progressively increased to maximum braking in about 11 seconds, and the airplane achieved a maximum deceleration of about -0.17 G at 0847:17, about 7 seconds after touchdown. Between 0847:19 and 0847:22, the deceleration increased briefly and then decreased until about 0847:23.5, 13.5 seconds after touchdown, as the wheel speeds decreased to 0, consistent with the application of the EPB and the beginning of a full, locked-wheel skid. The wheels remained locked until the airplane came to rest. During the skid, the deceleration steadily increased, before decreasing again to as the airplane passed the end of the runway at 0847:37.4. The airplane exited the runway about 27 seconds after touchdown at a groundspeed of about 61 knots.

The performance study determined that, after the airplane touched down, the computed braking friction coefficient increased steadily as the brake pedals were depressed, reaching a peak of about 0.16 before decreasing steadily to about 0.06 after the EPB was applied and the airplane entered a full, locked-wheel skid; this decrease is consistent with research indicating that the braking friction achieved in a full locked-wheel skid (a braking slip ratio of 1.0) is significantly less than the maximum braking friction coefficient that can be achieved at lower slip ratios. However, even before the EPB was applied, the computed braking friction coefficient was significantly lower than what would have been predicated using models prescribed in 14 CFR Part 25 for computing accelerate-stop distances on a wet runway. The braking friction coefficient was also significantly lower than that implied by the unfactored, wet runway landing distances published in the EMB-505 POH, which are computed as 25% greater than the unfactored (demonstrated) landing distances on a dry runway.

"However, the braking friction coefficient achieved during the accident was consistent with the predicted braking friction coefficient using a National Aeronautics and Space Administration (NASA) model that is based on runway friction measurements taken with a Continuous Friction Measurement Equipment (CFME) device."

"The decrease in braking friction coefficient after the EPB was applied is consistent with research indicating that the braking friction achieved in a full locked-wheel skid (a braking slip ratio of 1.0) is significantly less than the maximum braking friction coefficient that can be achieved at lower slip ratios"

As part of the performance study, the NTSB and the parties to the investigation conducted tests on runway 1 at CXO to measure the runway macrotexture depth and the cross slope. Based on the results of the runway tests, the performance study determined, taking into account a rainfall rate of 0.3 inch per hour and the runway macrotexture and cross slope, the accident landing gear would have encountered a maximum water depth of about 0.006 inch, which was far below the 3 mm (0.017 inch) that the EASA Acceptable Means of Compliance 25.1591 considered a "flooded" runway. Therefore, it is unlikely that the accident airplane experienced dynamic hydroplaning during the landing and that the low wheel braking friction coefficient levels resulted from viscous hydroplaning, which is associated with the buildup of water pressure due to viscosity.

The Phenom 300 Quick Reference Handbook (QRH) provided landing distance tables for various aircraft configurations and runway conditions. The QRH showed the unfactored runway distance required for a landing weight of 15,483 lbs and flaps 3 configuration to be 2,541 ft for a dry runway, 2,922 ft for a wet runway, and 4,885 ft for a contaminated runway (1/8-inch-deep water).

The performance study determined that, if the EPB had not been set and the braking friction had continued at levels attained early in the landing roll, then the airplane would have come to a stop about 4,669 ft from the threshold with 331 ft of runway remaining. The study noted that this level of braking friction is considerably lower than that underlying the wet runway landing distance in the AFM and is also lower than that specified by a wet runway model used in FAA advisory circulars (AC) and Part 25 certification regulations. Although the expected stopping distance of 4,669 ft was close to the EMB-505 AFM "contaminated (1/8 in water)" distance of 4,885 ft, the study noted that the runway characteristics and rainfall rate on the day of the accident precluded this runway condition. The study concluded that the braking friction deficit observed in this and other accidents examined during the course of this investigation showed that the airplanes' stopping performance was more consistent with AFM landing distances for runways contaminated with standing water than for runways that were merely "wet" even though it was determined that the runways involved could not have been flooded.

The performance study also noted that, although the achieved braking friction was lower than that specified by the model used in the FAA regulations and ACs for a wet runway, the FAA model friction level was closer to the achieved friction than the friction level implied by the wet-runway landing distances in the EMB-505 AFM. That is, the friction implied by the AFM wet-runway landing distances was even higher than that predicted by the FAA model, whereas the FAA model itself overpredicted the friction level for this accident. Further, Embraer provided data that showed the deceleration recorded for the time interval before the EPB was applied during the accident flight was consistent with the results obtained from a simulation using the optimized performance analyzer software based on the expected brake coefficient prescribed in AMC 25.1591 for standing water contamination (3 mm) and contaminated drag based on flight test data produced for EASA certification purposes.

The performance study concluded that, based on the runway characteristics and rainfall rate at the time of the accident, the water depth on the runway was well below 3 mm but that the braking friction coefficient achieved before the EPB was engaged closely matched that modeled for a water depth greater than 3 mm. Therefore, the circumstances of this accident indicate that some wet runways may provide friction levels closer to those used to model flooded runways than to those implied in the AFM wet runway landing distances even when the runway is not flooded.

See the Airplane Performance Study in the docket for this accident for additional details.

ADDITIONAL INFORMATION

NetJets Flight Operations Manual (FOM) and AFM Landing Distance Information
NetJets' FOM states that "every landing requires an adjustment to planned landing distance. The type of operation [that is, Part 91, 91K, or 135] dictates which adjustments are applied." The "planned landing distance" is the unfactored AFM dry landing distance for the airplane.

The FOM defined a contaminated runway as one in which more than 25 percent of the required runway length, within the width being used, is covered by standing water or slush deeper than 1/8 inch or accumulation of snow or ice and a wet runway as one in which its surface is reflective.

For dispatching a flight to a runway that is expected to be wet at the time of arrival, the FOM stated that, for Part 91 flights, the required landing distance is the unfactored wet landing distance specified in the AFM's FAA-approved landing performance data or the AFM's advisory data with no safety factor applied. However, in practice, NetJets dispatchers divided the unfactored AFM distance by 0.8, which resulted in a required landing distance greater than that specified in the FOM. For Parts 91K and 135 flights, the required landing distance was the unfactored dry landing distance from the AFM, divided by a safety factor of 0.6 with an additional safety factor of 15% applied.

For all operations, the FOM also required pilots to perform a landing performance assessment to recalculate the required landing distance "if weather, runway surface condition, aircraft status, or any other relevant factor has degraded from those shown in the flight release package." An additional safety factor of 15% must then be added to the recalculated distance.

The Embraer AFM, "Landing Technique," stated that the performance data are based on the following:

- Steady three degree angle approach at V_{ref} in landing configuration;
- V_{ref} airspeed maintained at runway threshold;
- Idle thrust established at runway threshold;
- Attitude maintained until MLG touchdown;
- Maximum braking applied immediately after MLG touchdown;
- Antiskid system operative.

NetJets Aircraft Operations Manual Arrival Briefing Information

NetJets Aircraft Operations Manual, Section 2.3.4, "Arrival Briefing," stated that, before conducting the arrival briefing, the crew should, if able, obtain the destination weather and landing information and program the flight management system (FMS). The pilot flying should transfer aircraft control and verify the FMS inputs and brief items pertaining to the arrival, including the arrival procedure (include altitude and airspeed constraints), NOTAMS, runway conditions, and landing performance assessment. These same items are also listed on the NetJets Normal Procedures Checklist under the Arrival Briefing section.

14 CFR Part 23 Certification Regulations

In accordance with 14 CFR Part 23 Section 23.75, "Landing distance,"

The horizontal distance necessary to land and come to a complete stop from a point 50 feet above the landing surface must be determined, for standard temperatures at each weight and altitude within the operational limits established for landing, as follows:

- (a) A steady approach at not less than V_{REF} , determined in accordance with §23.73 (a), (b), or (c), as appropriate, must be maintained down to the 50 foot height and—

- (1) The steady approach must be at a gradient of descent not greater than 5.2 percent (3 degrees) down to the 50-foot height.
- (2) In addition, an applicant may demonstrate by tests that a maximum steady approach gradient steeper than 5.2 percent, down to the 50-foot height, is safe. The gradient must be established as an operating limitation and the information necessary to display the gradient must be available to the pilot by an appropriate instrument.
- (b) A constant configuration must be maintained throughout the maneuver.
- (c) The landing must be made without excessive vertical acceleration or tendency to bounce, nose over, ground loop, porpoise, or water loop.
- (d) It must be shown that a safe transition to the balked landing conditions of §23.77 can be made from the conditions that exist at the 50 foot height, at maximum landing weight, or at the maximum landing weight for altitude and temperature of §23.63 (c)(2) or (d)(2), as appropriate.
- (e) The brakes must be used so as to not cause excessive wear of brakes or tires.
- (f) Retardation means other than wheel brakes may be used if that means—
 - (1) Is safe and reliable; and
 - (2) Is used so that consistent results can be expected in service.
- (g) If any device is used that depends on the operation of any engine, and the landing distance would be increased when a landing is made with that engine inoperative, the landing distance must be determined with that engine inoperative unless the use of other compensating means will result in a landing distance not more than that with each engine operating.

Section 23.1587, "Performance Information," stated the following:

- (a) For all airplanes, the following information must be furnished—
 - ...
 - (3) The landing distance, determined under §23.75 for each airport altitude and standard temperature, and the type of surface for which it is valid;
 - (4) The effect on landing distances of operation on other than smooth hard surfaces, when dry, determined under §23.45(g); and
 - (5) The effect on landing distances of runway slope and 50 percent of the headwind component and 150 percent of the tailwind component.

FAA Safety Alert for Operators (SAFO)

The FAA had previously issued two SAFOs that were relevant to the circumstances of this accident. SAFO 06012, "Landing Performance Assessments at Time of Arrival (Turbojets)," dated August 31, 2006, stated the following:

This SAFO urgently recommends that operators of turbojet airplanes develop procedures for flightcrews to assess landing performance based on conditions actually existing at time of arrival, as distinct from conditions presumed at time of dispatch. ... Once the actual landing distance is determined an additional safety margin of at least 15% should be added to that distance.

SAFO 06012 noted that, the dry-runway landing distances established during flight test and that are the basis for the factored landing distances used by dispatch, are shorter than the landing distances achieved in practice. In addition, AFM landing distances for wet and

contaminated runways may also be based on the minimum dry distances obtained during flight tests. Consequently, landing distances on wet or contaminated runways computed from AFM data with little or no additional safety margin may be too short for normal operations. The SAFO recommended a conservative approach to assessing the landing distance requirements, including using the most adverse reliable braking action report or expected conditions for the runway and using values for air distances and approach speeds that are representative of actual operations. The SAFO recommended that a 15% safety margin then be added to the computed (unfactored) landing distance because "the FAA considers a 15% margin between the expected actual airplane landing distance and the landing distance available at the time of arrival as the minimum acceptable safety margin for normal operations."

SAFO 15009, "Turbojet Braking Performance on Wet Runways," dated August 11, 2015, warned that "the advisory data for wet runway landings may not provide a safe stopping margin under all conditions" and stated the following:

Several recent runway landing incidents/accidents have raised concerns with wet runway stopping performance assumptions. Analysis of the stopping data from these incidents/accidents indicates the braking coefficient of friction in each case was significantly lower than expected for a wet runway as defined by the Federal Aviation Administration (FAA) in Federal Air Regulation (FAR) 25.109 and Advisory Circular (AC) 25-7C methods. These incidents/accidents occurred on both grooved and un-grooved or non-Porous Friction Course overlay (PFC) runways. The data indicates that applying a 15% safety margin to wet runway time-of-arrival advisory data, as recommended by SAFO 06012, may be inadequate in certain wet runway conditions...

The root cause of the wet runway stopping performance shortfall is not fully understood at this time; however, issues that appear to be contributors are runway conditions such as texture (polished or rubber contaminated surfaces), drainage, puddling in wheel tracks and active precipitation. Analysis of this data indicates that 30 to 40 percent of additional stopping distance may be required in certain cases where the runway is very wet, but not flooded.... Possible methods of applying additional conservatism when operating on a runway which experience has shown degraded when very wet are assuming a braking action of medium or fair when computing time-of-arrival landing performance or increasing the factor applied to the wet runway time-of-arrival landing performance data.

Advisory Circular 91-79A

The FAA issued AC 91-79A, "Mitigating the Risks of a Runway Overrun Upon Landing," on September 17, 2014. The AC stated the following:

DISCUSSION – HAZARDS ASSOCIATED WITH RUNWAY OVERRUNS

j. A Wet or Contaminated Runway. Landing distances in the manufacturer-supplied AFM provide performance in a flight test environment that is not necessarily representative of normal flight operations. For those operators conducting operations in accordance with specific FAA performance regulations, the operating regulations require the AFM landing distances to be factored to ensure compliance with the pre-departure landing distance regulations. These factors should account for pilot technique, wind and runway conditions, and other items stated above. Pilots and operators should also account for runway conditions at the

time of arrival (TOA) to ensure the safety of the landing. Though the intended audience of SAFO 06012 is turbojet airplanes, it is highly recommended that pilots of non-turbojet airplanes also follow the recommendations in SAFO 06012.

NTSB Safety Recommendations

As a result of previous accidents, the NTSB had issued Safety Recommendations A-07-57 and 61. Safety Recommendation A-07-57 asked the FAA to immediately require all 14 CFR Parts 121, 135, and 91 subpart K operators to conduct arrival landing distance assessments before every landing based on existing performance data, actual conditions, and incorporating a minimum safety margin of 15 percent. Safety Recommendation A-07-61 asked the FAA to require all 14 CFR Parts 121, 135, and 91 subpart K operators to accomplish arrival landing distance assessments before every landing based on a standardized methodology involving approved performance data, actual arrival conditions, a means of correlating the airplane's braking ability with runway surface conditions used the most conservative interpretation available, and including a minimum safety margin of 15 percent. Safety Recommendation A-07-57 is currently classified "Closed—Unacceptable Action," and Safety Recommendation A-07-61 is currently classified "Open—Unacceptable Response." See the Airplane Performance Study in the docket for this accident for additional details.

Postaccident Safety Actions

Netjets Actions

On September 11, 2015, NetJets issued Flight Operations Bulletin (FOB) 15-06, "Landing Considerations for Wet Untreated Runways." The FOB instructed pilots to determine if the runway had a treated (grooved or porous friction) overlay during the arrival briefing. It added that pilots should conduct a landing performance assessment using the AFM contaminated runway performance data for the lowest contamination depth when the following three conditions existed: 1) the runway does not have a treated surface, 2) thrust reversers are deferred or not installed, and 3) the airport is reporting rain or heavy rain.

On December 14, 2016, NetJets issued FOB 14-12, "Use of Emergency Braking." The FOB instructed pilots to continue to use normal antiskid braking unless there is a positive indication of a brake system failure, at which time, they should apply corresponding aircraft AFM or QRH procedures.

In addition, NetJets added the following to its AOM:

2.26.4 Ground Spoilers

Ground Spoilers are deployed automatically upon touchdown with thrust levers at idle.

Deployment failure of spoilers causes reduced normal braking effectiveness and may be misinterpreted as a brake failure. Do not engage the emergency brake system unless total brake failure is indicated (i.e., EICAS [engine indication and crew alerting system] message of a failed system affecting normal braking).

2.26.5 Braking

For optimum braking efficiency, smoothly apply constant brake pressure after touchdown of the main landing gear. Do not pump brakes.

On short of slippery runways, apply maximum braking. Maintain steady and increasing brake pressure, allowing the anti-skid system to function.

NetJets highlighted runway excursions as part of its flight crew training, and the factual information developed in this investigation was used as part of the training. In addition, NetJets worked with Flight Safety International to enhance its brake and antiskid systems training.

Embraer Actions

On November 5, 2014, Embraer issued Flight Operation Letter (FOL) PHE505-018/14, "Landing Procedure Best Practices and Recommendations." Revision 1 was issued on August 14, 2015, and Revision 2 was issued on June 6, 2016. The FOL highlighted some information contained in FAA AC 91-79A and added information specific to the Phenom fleet. The letter stated that, due to the antiskid function, the BCU will automatically calculate the maximum pressure delivered to the brakes, based on the pavement condition. As a result, pilots will notice lower deceleration on a contaminated runway compared to a dry runway.

The FOL contained the following:

CAUTION: The emergency parking brake will always deliver worse performance when compared to the normal brakes with anti-skid protection. Its use is only recommended on abnormal conditions, when the BRK FAIL CAS message is annunciated. In these conditions, applying the landing correction factors, determinate by the QRH, are mandatory.

The FOL further stated,

By definition, a wet runway is a pavement covered by less than 3mm (0.125") of water and the standing water has more than 25% of the pavement covered with more than 3mm of water...Also, be careful when evaluating a light rain over a non-grooved runway or a concrete polished surface. This may result in a slippery surface, which reduces braking action. In this case, the standing water numbers are more recommended than wet.

The FOL states, "CAUTION: The emergency parking brake will always deliver worse performance when compared to the normal brakes with anti-skid protection. Its use is only recommended on abnormal conditions, then the BRK FAIL CAS message is annunciated. In these conditions, applying the landing correction factors, determinate by the QRH, are mandatory."

History of Flight

Landing-landing roll	Runway excursion (Defining event) Collision with terr/obj (non-CFIT) Landing gear collapse
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Pilot Information

Certificate:	Airline Transport; Commercial	Age:	63, Male
Airplane Rating(s):	Multi-engine Land; Single-engine Land	Seat Occupied:	Left
Other Aircraft Rating(s):	Balloon	Restraint Used:	5-point
Instrument Rating(s):	Airplane	Second Pilot Present:	Yes
Instructor Rating(s):	None	Toxicology Performed:	No
Medical Certification:	Class 1 With Waivers/Limitations	Last Medical Exam:	04/03/2014
Occupational Pilot:	Yes	Last Flight Review or Equivalent:	05/12/2014
Flight Time:	13466 hours (Total, all aircraft), 322 hours (Total, this make and model)		

Pilot Information

Certificate:	Airline Transport; Commercial	Age:	42, Male
Airplane Rating(s):	Multi-engine Land; Single-engine Land	Seat Occupied:	Right
Other Aircraft Rating(s):	None	Restraint Used:	5-point
Instrument Rating(s):	Airplane	Second Pilot Present:	Yes
Instructor Rating(s):	None	Toxicology Performed:	No
Medical Certification:	Class 1 Without Waivers/Limitations	Last Medical Exam:	07/22/2014
Occupational Pilot:	Yes	Last Flight Review or Equivalent:	05/12/2014
Flight Time:	9861 hours (Total, all aircraft), 361 hours (Total, this make and model)		

Aircraft and Owner/Operator Information

Aircraft Manufacturer:	EMBRAER	Registration:	N322QS
Model/Series:	EMB 505	Aircraft Category:	Airplane
Year of Manufacture:	2013	Amateur Built:	No
Airworthiness Certificate:	Commuter	Serial Number:	50500165
Landing Gear Type:	Retractable - Tricycle	Seats:	9
Date/Type of Last Inspection:	07/17/2014, AAIP	Certified Max Gross Wt.:	18387 lbs
Time Since Last Inspection:		Engines:	2 Turbo Fan
Airframe Total Time:	597.7 Hours	Engine Manufacturer:	P&W CANADA
ELT:	C126 installed, not activated	Engine Model/Series:	PW535E
Registered Owner:	NETJETS SALES INC, et al	Rated Power:	3360 lbs
Operator:	NetJets Aviation, Inc.	Air Carrier Operating Certificate:	On-demand Air Taxi (135)

Meteorological Information and Flight Plan

Conditions at Accident Site:	Instrument Conditions	Condition of Light:	Day
Observation Facility, Elevation:	CXO, 245 ft msl	Observation Time:	0841 CDT
Distance from Accident Site:	0 Nautical Miles	Direction from Accident Site:	0°
Lowest Cloud Condition:	Few / 500 ft agl	Temperature/Dew Point:	23°C / 22°C
Lowest Ceiling:	Broken / 8000 ft agl	Visibility	2 Miles
Wind Speed/Gusts, Direction:	Calm	Visibility (RVR):	
Altimeter Setting:	29.93 inches Hg	Visibility (RVV):	
Precipitation and Obscuration:	Heavy - Rain; Mist		
Departure Point:	Nashville, TN (BNA)	Type of Flight Plan Filed:	IFR
Destination:	Conroe, TX (CXO)	Type of Clearance:	IFR
Departure Time:	0706 CDT	Type of Airspace:	Class D

Airport Information

Airport:	Lone Star Executive Airport (CXO)	Runway Surface Type:	Concrete
Airport Elevation:	245 ft	Runway Surface Condition:	Wet
Runway Used:	01	IFR Approach:	RNAV
Runway Length/Width:	5000 ft / 100 ft	VFR Approach/Landing:	Straight-in

Wreckage and Impact Information

Crew Injuries:	2 None	Aircraft Damage:	Substantial
Passenger Injuries:	N/A	Aircraft Fire:	None
Ground Injuries:	N/A	Aircraft Explosion:	None
Total Injuries:	2 None	Latitude, Longitude:	30.360000, -95.414444 (est)

Administrative Information

Investigator In Charge (IIC): Pamela S Sullivan **Adopted Date:** 04/19/2017

Additional Participating Persons: James Moore; FAA; Houston, TX
Patrick Hempen; FAA; Washington, DC
Brian Clark; NetJets; Columbus, OH
Richard Meikle; NetJets; Columbus, OH
Nuno Aghdassi; NetJets; Columbus, OH
Capt Bob Ferguson; NJASAP; Gahanna, OH
Daniel Marimoto; Embraer; FN
Murillo Boery; CENIPA; FN
Peter Combs; AAIB; FN
John Smith; Meggitt; FN

Publish Date: 04/20/2017

Investigation Docket: <http://dms.nts.gov/pubdms/search/dockList.cfm?mKey=90106>

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