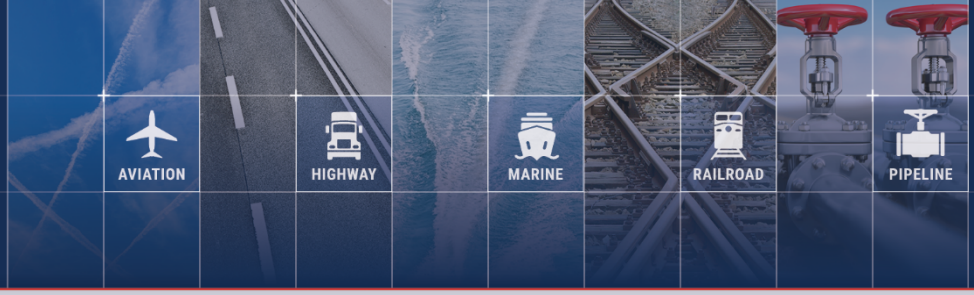

Aviation Investigation Final Report

Location:	Chicago, Illinois	**Accident Number:**	DCA20LA013
Date & Time:	November 11, 2019, 07:42 Local	**Registration:**	N619AE
Aircraft:	Embraer EMB145	**Aircraft Damage:**	Substantial
Defining Event:	Runway excursion	**Injuries:**	41 None
Flight Conducted Under:	Part 121: Air carrier - Scheduled		

Analysis

While the airplane was on short final approach to runway 10L, the tower controller issued instructions to the accident flight crew to go-around. (The controller did not provide a reason for the go-around instruction.) The flight crew performed a go-around maneuver and subsequently discussed, with the company dispatcher, the possibility of diverting to the alternate airport or changing the alternate airport to one closer to the airplane's position. However, the flight crew elected to make another approach to the destination airport.

During the second approach to runway 10L, the tower controller informed the flight crew that the runway condition code was 5/5/5, which indicated "good" braking action across all three runway zones (touchdown/midpoint/rollout). However, the controller also informed the crew that other flight crews had reported the braking action as "medium to poor" until taxiway N3 (which was located about halfway down the runway) and then "poor" past that point. The controller cleared the airplane to land and reported that the wind was from 360° at 17 knots with gusts to 24 knots. Given the runway orientation, the steady-state wind speed would have resulted in a crosswind component of about 16 knots. The company's maximum crosswind limit during landing was 30 knots for a dry runway or if the braking action is reported as "good".

The airplane touched down on the runway centerline, but, as the captain applied the brakes and reverse thrust, the airplane moved off the centerline. The crew stated the airplane started swerving to the right when its indicated airspeed was about 80 knots. As the captain applied corrections to maneuver back to the centerline, the airplane started to slide to the left. The captain stated that he applied maximum reverse power and brakes but that the airplane continued to slide to the left.
Flight data recorder (FDR) data indicated that after landing, thrust reverser deployment and brake application, the airplane was tracking slightly right when the captain was commanding

slightly left. At 80 knots, the airplane veered to the left and the captain commanded airplane nose right rudder. However, rudder effectiveness at slower airspeeds and with thrust reversers is reduced and the left turn was not arrested. Data also shows that no more than +/- 3 degrees of rudder deflection was used.

The first officer stated that the airplane "experienced an uncommanded swerve" to the left near taxiway N1, which was about one-third of the way down the runway from the approach end. The airplane subsequently slid off the runway at an airspeed of about 60 knots and onto the grass on the left side of the runway. Postaccident examination of the airplane systems revealed no anomalies that would have precluded normal operation.

Light wet snow had started falling at the airport about 3.5 hours before the time of the accident, and about 1.6 inches of snow accumulation was reported at 0600. Clearing operations had been performed on runway 10L, and it was reopened about 1.5 hours before the accident with a runway condition code of 5/5/5 and conditions assessed as 90% wet and 10% with 1/8 inch of wet snow across all three runway zones. A field condition notice to air mission reflecting those conditions was issued at 0624. Given that light wet snow was falling at the time, a reassessment of the runway conditions needed to occur within 90 minutes of the previous assessment, and a 90-minute pavement inspection timer was set in the air traffic control tower.

As snow clearing operations on runway 10L were concluding, airport operations personnel began conducted clearing operations on the two other parallel runways (10C and 10R) on the south side of the airport. Runway 10C remained closed until about 3 minutes before the accident, and runway 10R had not been reopened at the time of the accident because conditions on that runway had not yet improved. Thus, at the time that the accident flight was cleared to land, runway 10L was the only runway on the south side of the airport being used for landing operations.

As previously stated, the tower controller informed the flight crew that the reported braking action for runway 10L was "medium to poor" until taxiway N3 and "poor" past that point. According to Envoy Air's *EMB-140/145 Aircraft Operations Manual*, which contained Federal Aviation Administration guidance about runway condition assessments, a pilot report of medium indicated that braking deceleration or directional control was "noticeably reduced," and a pilot report of poor indicated that braking deceleration or directional control was "significantly reduced." Both the captain and the first officer indicated that, according to company guidance, the Runway condition codes are "controlling" and that pilot reports are advisory. Thus, it was reasonable for the flight crew to attempt to land on the runway based on the reported Runway condition code of 5/5/5.

The captain's use of maximum reverse thrust and braking appeared to be consistent with his training. Specifically, the captain stated that he was trained to land on a contaminated runway by applying the brakes evenly and using maximum reverse until the airplane decelerated to about 80 knots. Envoy Air's guidance stated that reverse thrust was the best aid in stopping on

slippery runways and that high levels of symmetrical reverse thrust early in the landing roll would provide the most stopping force.

The captain also stated that he was trained that rudder effectiveness was reduced when using reverse thrust. In this case, the reduced rudder effectiveness was appropriate because the flight crew's use of reverse thrust helped slow the airplane. Additionally, Envoy Air's guidance stated that, at lower speeds, nosewheel steering and differential braking would be primarily used for directional control. In this case, the use of the differential braking and nosewheel steering might have helped the airplane track along the runway centerline, but the airplane's stopping time (and distance) would likely have increased.

After runway 10L reopened at 0618, the controller requested braking action reports from landing airplanes. The flight crew of the first airplane to land on the runway reported braking action as poor. Multiple flight crews of airplanes that landed afterward reported that braking action was medium until taxiway N3 and poor after that point. One flight crew reported that it became "really hard to hold the centerline" after taxiway N3 because of the crosswind. Further, as the controller was issuing instructions to a flight crew for exiting the runway, she described the conditions at taxiway N3 as "slick." Thus, the conditions on runway 10L had deteriorated and were no longer consistent with the previously published field condition NOTAM indicating that the Runway condition code was 5/5/5.

The airport's Snow and Ice Control Plan stated that two consecutive reports of poor braking action would trigger either a runway closure or a runway assessment. Although two consecutive reports of poor braking action were not received for the touchdown zone of the runway, multiple reports of poor braking action reports were received for the midpoint zone, which were not consistent with the airport's previous assessment of the runway.

The southside snow coordinator had been monitoring the status of runway 10L from the air traffic control tower and was aware of the reports of medium and poor braking action. About 0730 (and with about 60 minutes of the 90-minute pavement inspection timer elapsed), he dispatched two airport operations supervisors in two vehicles to conduct friction and condition assessments of runway 10L. One of the supervisors requested clearance onto the runway, but the controller instructed both vehicles to hold short of the runway at their position (taxiway Z). About 2 minutes later, the other supervisor notified the controller that both vehicles were holding short of runway 10L, and the controller acknowledged this information and repeated the hold-short instruction. The accident occurred about 7 minutes 17 seconds after the first airport operations supervisor initially requested access to the runway.

Although airport operations supervisors were standing by to conduct an assessment of runway 10L before the 90-minute pavement inspection timer had elapsed, the available evidence for this accident precluded a determination of why the vehicles were not cleared onto the runway before the accident landing.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be:

The flight crew's inability to maintain the airplane on the runway centerline after touchdown due to the reduced braking action resulting from the deteriorating weather conditions, which caused the airplane's departure from the runway surface. Contributing to the accident were the delay in performing the runway assessment for undetermined reasons and failure to close the runway. Also contributing to the accident was the controller's failure to advise the accident flight crew that braking action was no longer consistent with the previously published notice to air mission, which described braking action as good across all three runway zones.

Findings

Environmental issues	(general) - Effect on equipment
Personnel issues	Delayed action - Airport personnel
Personnel issues	Identification/recognition - ATC personnel

Factual Information

History of Flight

Landing	Runway excursion (Defining event)

On November 11, 2019, about 0742 central standard time, American Eagle flight 4125, operated by Envoy Air, an Embraer EMB-145, N169AE, departed the left side of runway 10L while landing at Chicago O'Hare International Airport (ORD), Chicago, Illinois, and the right main landing gear collapsed. None of the 41 crewmembers and passengers aboard the airplane were injured, and the airplane sustained substantial damage. The flight was operating under Title 14 *Code of Federal Regulations* Part 121 as a domestic passenger flight that originated from Piedmont Triad International Airport (GSO), Greensboro, North Carolina.

The captain stated that, while at the gate at GSO, he and the first officer reviewed the expected weather conditions for ORD. The flight departed about 0522 (0622 local time). The captain was the pilot flying, and the first officer was the pilot monitoring. While enroute, the flight crew monitored the weather at ORD; the reported visibility was between 3/4 and 1 mile.

The Chicago approach controller initially assigned the flight to runway 9L. While the airplane was on the downwind leg of the approach, the controller changed the landing runway to 10L because runway 9L was closed for snow removal.

When the airplane was on short final approach to runway 10L, the tower controller instructed the flight to go-around. According to the cockpit voice recorder (CVR), the flight crew did not know the reason for the go-around. After conducting the go-around. the flight crew contacted the flight dispatcher and discussed various options, including diverting to the alternate airport (Cincinnati/Northern Kentucky International Airport, Hebron, Kentucky) or changing the alternate airport to one that was closer to the airplane's position at the time. The crew elected to make another approach to ORD. The Chicago approach controller provided vectors for the approach to runway 10L. The airplane intercepted the localizer and glideslope for the runway.

According to the CVR transcript, at 0739:34, the first officer notified the tower controller that the flight had arrived at the final approach fix. About 2 seconds later, the tower controller stated that the "RCC [runway condition code] is 555 – braking medium to poor up to [taxiway] November 3 and poor past [that point]." The first officer acknowledged this information. (A runway condition code of 5/5/5 indicated good braking action on each one-third of the runway, as discussed in the Airport Information and Additional Information sections of this report. Taxiway N3 was about halfway down the runway.)

At 0740:28, the controller cleared the flight to land and stated that the wind was from 360° at 17 knots with gusts to 24 knots. The first officer acknowledged the clearance. After the

accident, the flight crewmembers reported that the approach was stable, and that the airplane broke out of the clouds when it was about 500 ft above ground level. According to flight data recorder (FDR) data, the autopilot was disengaged at 0741:30, but vertical and lateral guidance remained on the flight director until touchdown.

At 0741:32, the first officer called, “runway in sight,” and the captain stated, “roger – landing.” At 0741:59, the CVR recorded a sound similar to the landing gear touching down, and the FDR showed that the inboard and outboard wheel brake pressure began to increase about 1 second later. At 0742:02, the thrust reversers were deployed, and the airplane’s groundspeed was 127 knots. About that time, the first officer stated, “stay on that centerline,” and the captain stated “yep” followed by expletives. At 0742:08 and 0742:12, the CVR recorded sounds similar to the airplane slowing down and sounds similar to reverse thrust increasing, respectively. At 0742:15 the airplane began to turn to the left with the thrust reverser levers still deployed.

At 0742:22, the CVR recorded sounds similar to the thrust reverse levers being moved to forward idle. As the reversers were stowed, the inboard and outboard wheel brake pressures increased, and the airplane continued to turn to the left. FDR data showed that, when the thrust reversers were stowed, the airplane’s groundspeed was 39 knots. Afterward, the captain stated an expletive and “ugh,” and the CVR recorded an increase in background noise. At 0742:29, the airplane’s vertical acceleration was 1.64 G, and its lateral acceleration was -0.85 G. About 1 second later, the CVR recorded the master warning “landing gear,” which continued until the end of the recording (at 0805:51).

After the accident, the captain reported that the airplane touched down on the runway centerline and that, as brakes were applied, the airplane moved off the centerline. The first officer reported that the airplane started swerving to the right when its indicated airspeed was about 80 knots. As the captain applied corrections to maneuver back to the centerline, the airplane started to slide to the left. The captain stated that he applied maximum reverse thrust and brakes but that the airplane continued to slide to the left at a speed of about 60 knots. The first officer stated that, at that time, the airplane “experienced an uncommanded swerve” toward taxiway N1, which was about one-third of the way down the runway from the approach end. FDR data shows that no more than +/- 3 degrees of rudder deflection was used.

The airplane subsequently slid off the end of the runway and onto the grass on the left side of the runway, as shown in figure 1. The right main gear collapsed when the airplane departed the runway surface and entered the grass area.

Figure 1. Airplane's resting position after runway excursion (Source: Envoy Air).

At 0742:32, the controller asked the flight crew if assistance was needed, and the first officer replied, "need assistance." After the accident, the captain reported that, because no fire was occurring, he determined that the passengers should remain aboard the airplane until emergency services and shuttle buses arrived. According to airport event logs, the Chicago Fire Department arrived on scene about 0747. No passengers requested medical assistance, and airport rescue and firefighting personnel helped to deplane the passengers and crew via the main cabin door and a rescue ramp. The first officer reported that the runway had snow and that the nearby taxiway was "very icy." The shuttle buses arrived at the assigned airport gate about 1 hour after the accident.

After the accident, the captain stated that he did not recall hearing any braking reports other than 5/5/5, and the first officer recalled that the controller reported "good" braking action before taxiway N3 and "3" (medium) past taxiway N3. Both pilots stated that, according to company guidance, the runway condition codes are "controlling" and that pilot reports are advisory.

Pilot Information

Certificate:	Airline transport; Commercial; Flight instructor	**Age:**	43,Male
Airplane Rating(s):	Single-engine land; Multi-engine land	**Seat Occupied:**	Left
Other Aircraft Rating(s):	None	**Restraint Used:**	5-point
Instrument Rating(s):	Airplane	**Second Pilot Present:**	Yes
Instructor Rating(s):	Airplane multi-engine; Airplane single-engine	**Toxicology Performed:**	No
Medical Certification:	Class 1 Without waivers/limitations	**Last FAA Medical Exam:**	September 9, 2019
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	September 19, 2019
Flight Time:	(Estimated) 3166 hours (Total, all aircraft), 1084 hours (Total, this make and model)		

Co-pilot Information

Certificate:	Airline transport; Commercial	**Age:**	35,Male
Airplane Rating(s):	Single-engine land; Multi-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):		**Toxicology Performed:**	No
Medical Certification:	Class 1 Without waivers/limitations	**Last FAA Medical Exam:**	July 8, 2019
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	May 13, 2019
Flight Time:	(Estimated) 2855 hours (Total, all aircraft), 1158 hours (Total, this make and model)		

Aircraft and Owner/Operator Information

Aircraft Make:	Embraer	**Registration:**	N619AE
Model/Series:	EMB145 LR	**Aircraft Category:**	Airplane
Year of Manufacture:	1998	**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	145101
Landing Gear Type:	Retractable - Tricycle	**Seats:**	54
Date/Type of Last Inspection:	November 11, 2019 Continuous airworthiness	**Certified Max Gross Wt.:**	50044 lbs
Time Since Last Inspection:		**Engines:**	2 Turbo fan
Airframe Total Time:	45985 Hrs at time of accident	**Engine Manufacturer:**	Allison
ELT:	C126 installed, not activated	**Engine Model/Series:**	AE3007C SER
Registered Owner:	American Airlines Inc	**Rated Power:**	7426 Lbs thrust
Operator:	Envoy Air Inc.	**Operating Certificate(s) Held:**	Flag carrier (121)
Operator Does Business As:	American Eagle	**Operator Designator Code:**	SIMA

Meteorological Information and Flight Plan

Conditions at Accident Site:	Instrument (IMC)	**Condition of Light:**	Day
Observation Facility, Elevation:	KORD	**Distance from Accident Site:**	0 Nautical Miles
Observation Time:	16:28 Local	**Direction from Accident Site:**	225°
Lowest Cloud Condition:	1600 ft AGL	**Visibility**	1 miles
Lowest Ceiling:	Overcast / 1600 ft AGL	**Visibility (RVR):**	
Wind Speed/Gusts:	18 knots / 26 knots	**Turbulence Type Forecast/Actual:**	/
Wind Direction:	350°	**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:	30.23 inches Hg	**Temperature/Dew Point:**	6°C / 7°C
Precipitation and Obscuration:			
Departure Point:	Greensboro, NC (KGSO)	**Type of Flight Plan Filed:**	IFR
Destination:	Chicago, IL (KORD)	**Type of Clearance:**	IFR
Departure Time:	06:22 Local	**Type of Airspace:**	Class B;Class D

ORD had an automated surface observing system (ASOS) that was augmented by certified weather observers. A review of the ASOS observations indicated that, on the day before the accident (November 10, 2019), precipitation started as light rain at 2036 and changed over to

light snow at 2351 with temperatures falling to -6.1°C (21°F). Snow ended at 1735 on the day of the accident (November 11); a total of 3 inches of snow was reported.

At 0551 on November 11, the ASOS reported 2 inches of snow on the ground with light snow continuing through the time of the accident. Low instrument flight rules conditions and a visibility under 1 statute mile prevailed at the time of the accident.

The ASOS 5-minute observation for 0740 resulted in a crosswind of 18 to 28 knots and a 3- to 5-knot tailwind component for landing on runway 10L. The ASOS also made 1-minute observations, which included the 2-minute average wind and the 5-second maximum wind. The 2-minute average wind at 0743 indicated that the crosswind component for landing on runway 10L was 15 knots with a 4-knot tailwind. The 5-second maximum wind showed a crosswind of 23 knots with a 6-knot tailwind.

Numerous pilot reports of light rime icing conditions in the ORD area were received during the time surrounding the accident. Pilot reports of braking action before the accident ranged from medium to poor, as further discussed in the Airport Information section.

Airport Information

Airport:	Chicago O'Hare KORD	**Runway Surface Type:**	Asphalt;Concrete
Airport Elevation:	680 ft msl	**Runway Surface Condition:**	Ice;Snow;Wet
Runway Used:	10L	**IFR Approach:**	ILS
Runway Length/Width:	13000 ft / 150 ft	**VFR Approach/Landing:**	

The runway 10L/28R pavement was in good condition and had precision runway markings, high-intensity runway edge lighting, and centerline and touchdown zone lighting. The runway was one of three south parallel runways (10L/28R, 10C/28C, and 10R/28L) at the airport.

Runway Conditions Before the Accident

On the day of the accident, pavement surface temperature data for the runway 10L touchdown zone showed that the temperature dropped below freezing from 32.5°F at 0559 to 28.8°F at 0604. The pavement surface temperature ranged from 28.0°F to 29.1°F between 0604 and the accident time. Airport operations personnel reported that snow accumulation on the pavement started about 0415 as light wet snow. Airport logs noted that the total snow accumulation at 0600 was 1.6 inches.

About 0537, runway 10L was closed for snow removal operations, which were conducted from about 0546 to 0621. (Runways 10C and 10R were open at that time.) According to the southside snow coordinator (who was working in the air traffic control tower [ATCT] after the

runway was cleared), two airport operations supervisors (AOS) conducted a surface assessment of runway 10L. The runway condition was reported as 90% wet and 10% with 1/8 inch of wet snow across all three runway zones (touchdown/midpoint/rollout). A friction assessment conducted about 0615 reported Mu readings of 61/45/61 (an average of 56), indicating good friction.

The southside snow coordinator stated that he issued a field condition notice to air mission (NOTAM) that reported runway 10L as runway condition code 5/5/5 given that the friction assessment results corresponded with the surface conditions. (This NOTAM was issued at 0624, about 1 hour 18 minutes before the accident.) The southside snow coordinator also stated that he reset the pavement inspection timer (used to track when a runway assessment should occur) for 90 minutes based on the light wet snow that was occurring. Runway 10L was reopened at 0618.

As snow clearing operations on runway 10L were concluding, airport operations personnel began clearing operations on parallel runways 10C and 10R. (Runway 10C remained closed until about 0739, and runway 10R had not been reopened at the time of the accident because Mu values from friction assessments remained low.)

The southside snow coordinator reported that he was monitoring the status of runway 10L from the ATCT and noted that there had been "alternating reports of medium and poor braking." (He did not hear two consecutive reports of poor braking action). The southside snow coordinator stated that he dispatched AOS personnel in two vehicles to assess the condition of runway 10L. The AOS in one of the vehicles recalled receiving the dispatch call about 0730 (which was about 30 minutes before the 90-minute pavement timer would have alerted in the ATCT).

When both vehicles arrived on taxiway Z (near the departure end of runway 10L), one AOS contacted the controller and requested that the vehicles be cleared to proceed onto runway 10L when able; the controller instructed the vehicles to hold short south of runway 10L. About 2 minutes later, the other AOS notified the controller that both vehicles were holding short of runway 10L; the controller acknowledged the transmission and repeated the hold-short instruction. While waiting for clearance onto the runway, both AOS personnel observed a few airplanes landing on the runway, and both AOS personnel heard the radio communications between the Envoy Air flight crew and the controller after the accident.

The ATCT communications transcript showed that 1 minute had elapsed between the time that the controller asked the accident flight crewmembers if they needed assistance and the clearance allowing the AOS' vehicles to proceed onto runway 10L. The transcript also showed that 8 minutes 17 seconds had elapsed between the AOS' initial contact with the controller and the controller's clearance of the vehicles onto the runway.

Runway Conditions After the Accident

One of the AOS personnel recalled that the runway had “complete coverage” of snow and that he had a hard time stopping his vehicle while approaching the location where the airplane came to rest. A runway surface assessment performed after the accident (between about 0801 and 0811) found that runway 10L was 100% covered with 1/8-inch of wet snow in the touchdown and midpoint zones and 100% covered with ¼-inch of wet snow in the rollout zone. The friction assessment recorded Mu readings of 24/22/23 (with an average reading of 23), indicating significantly reduced friction.

Pilot Reports of Braking Action Before Accident

Flight crews of arriving and departing airplanes provided the following pilot reports about the braking action on runway 10L:

- SkyWest Airlines flight 1534, the first airplane to land on runway 10L after it was reopened, reported that the braking was “poor.”

- United Airlines flight 2116 reported that the braking action was “medium” but that, after the airplane reached A3, the braking action “went down to poor.”

- Republic Airways flight 3568 reported that the braking action “was pretty solid up to [taxiway] N3 and pretty poor after that.”

- United Airlines flight 2043, which was departing, reported, “takeoffs not a good idea slide sideways.”

- United Airlines flight 203 reported, “we’re still…sliding down the runway a little bit here, United 203 braking is poor…[taxiway] N3 is not going to work.” After the airplane had turned off the runway, the controller asked the flight crewmembers if they would agree that braking action “got slick” at taxiway N3, and a crewmember responded, “yeah, that sounds like it would make sense…it gets really hard to hold the centerline after that because of the crosswind.”

- Delta Air Lines flight 851 reported that the braking action was “maybe medium.”

- Trans States Airlines flight 4790 reported that braking action was “poor.”

Other recorded transmissions demonstrated the conditions on runway 10L before the accident landing. Such transmissions included the following:

- The controller told the flight crew of an airplane holding for takeoff, “it’s going to be a few minutes I don’t trust that this heavy [jet] is not going to roll down to the end with the…poor braking action.” (The controller was referring to China Southern Airlines flight 431, which was arriving.)

- American Airlines flight 140 had been holding for departure but then told the controller they would be unable to depart from runway 10L due to poor braking action. The controller then worked with this flight crew and others of airplanes waiting to depart to clear them to different runways or back to the gate.

- SkyWest Airlines flight 3208 was on approach to runway 10L but then informed the controller that the airplane would be going around due to the braking action report.

- When the controller was providing SkyWest Airlines flight 3115 instructions for exiting the runway, the controller stated, "turn left at N3 or if you have it [taxiway] T…I know it's slick."

- When All Nippon Airways flight 112 checked in for a landing clearance, the controller stated, "braking action poor reported by an E145."

Airport Snow and Ice Control Plan

The ORD Snow and Ice Control Plan, which the Federal Aviation Administration (FAA) approved on November 28, 2017, was part of the airport certification manual. The plan was consistent with the guidance outlined in FAA Advisory Circular 150/5200-30, Airport Field Condition Assessments and Winter Operations Safety. The plan included personnel responsibilities, procedures for conducting runway condition assessments, triggers for initiating snow removal operations, surface assessment reporting, and NOTAM issuance during snow events.

Regarding the triggers for initiating snow removal operations, the plan stated the following: "Initial snow removal operations commence at the onset of snowfall, after there is sufficient snow on the runway and before a 1/4 to 1/2 inch of snow accumulates." The plan also stated that reports of poor braking action would trigger pavement assessments.

Regarding procedures for surface assessment reporting, the plan discussed the need to validate runway condition codes as part of the runway condition assessment matrix (RCAM) process. (The RCAM appears in the Additional Information section.) Specifically, the plan noted the following:

> *Temperatures near and above freezing (e.g., at 26.6 deg F… and warmer) may cause contaminants to behave more slippery than indicated by the runway condition code given in the RCAM. At these temperatures, airport operators should exercise a heightened awareness of airfield conditions and should downgrade the RwyCC [runway condition code] if appropriate.*

The plan also stated that two consecutive reports of poor braking action would trigger either a

runway closure (if the continuous runway monitoring procedure was not in effect) or a runway assessment (if the procedure was in effect). In addition, the plan stated that friction assessments should be conducted immediately after any aircraft incident or accident on a runway.

Wreckage and Impact Information

Crew Injuries:	3 None	**Aircraft Damage:**	Substantial
Passenger Injuries:	38 None	**Aircraft Fire:**	None
Ground Injuries:		**Aircraft Explosion:**	None
Total Injuries:	41 None	**Latitude, Longitude:**	41.582778,-87.542221

Post-accident aircraft examination found no anomalies with the nosewheel steering system or the spoiler system. The braking system was checked in accordance with the Aircraft Maintenance Manual with no faults found. None of the tires showed any signs of rubber reversion, flat spotting, or abnormal wear. The rudder system and thrust reversers passed their respective operational tests with no faults found.

The nosewheel steering manifold assembly was functionally tested, and it was observed that during test setup, with hydraulic pressure applied but no electrical command input to the unit, the C2 output port pressure increased while the C1 output port pressure remained near 0 psi. While this behavior was unexpected by the manufacturer, when electrical command input was supplied to the nosewheel steering manifold assembly (as it would have been during the accident), the unit performed as expected. The electrohydraulic servo valve, which is a subcomponent of the nosewheel steering manifold assembly, was removed for additional testing. A new electrohydraulic servo valve was placed in the nosewheel steering manifold assembly for functional testing, and the assembly passed all performed tests.

Functional testing of the electrohydraulic servo valve was performed according to the manufacturer's acceptance test procedure, and the unit met the as-new acceptance test limits for all performed tests except for a slight exceedance observed during the flow gain test. According to the manufacturer, this flow gain exceedance could result in a small increase in the speed of the nosewheel deflection in the commanded direction but would not cause a change to the commanded direction or result in an uncommanded nosewheel turn. The manufacturer also stated that that this amount of flow gain exceedance was typically caused by wear and was common to electrohydraulic servo valves with a significant number of service hours.

Teardown of the electrohydraulic servo valve revealed a small particle of foreign object debris (FOD) found adhered to the armature near the top of the air gap on the right side. The FOD was removed, and the National Transportation Safety Board's Materials Laboratory determined that the FOD was consistent with an organic material, the source of which was not identified. Following the removal of the FOD, the plots for pressure gain, flow gain, internal leakage, and noise were re-run. While some performance changes were identified in the plots, the manufacturer indicated that the changed values passed the as-new ATP requirements both before and after the FOD was removed.

Additional disassembly of the electrohydraulic servo valve revealed that the filter seals were beginning to split on both the inner and outer diameters in the circumferential direction. Examination of the seals under magnification revealed no material loss of the seal.

The nosewheel steering electronic control module, feedback unit potentiometer assembly, rudder pedal potentiometer assembly, and brake control unit were functionally tested and passed all tests.

Additional Information

Envoy Air's *EMB-140/145 Aircraft Operations Manual* included the figure below, which was based on the information in FAA Advisory Circular 91-79A, Mitigating the Risks of a Runway Overrun Upon Landing (dated September 17, 2014).

Airport Operator Assessment Criteria			Control/Braking Assessment Criteria		Landing Distance Column Used
Runway Condition Description	Mu	Code	Deceleration of Directional Control Observation	Pilot Reported Braking Action	
• Dry		6	-	-	Dry
• Frost • Wet (includes damp and less than 1/8 inch depth of water) **Less than 1/8 inch (3mm) depth of:** • Slush • Dry Snow • Wet Snow	40 or higher	5	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good	Good
-15°C and colder outside air temperature: • Compacted Snow	39-30	4	Braking deceleration OR directional control is between Good and Fair (Medium).	Good to Medium	Medium
• Slippery When Wet (wet runway) • Dry Snow or Wet Snow (any depth) over Compacted Snow **1/8 inch depth or greater of:** • Dry Snow • Wet Snow **Warmer than -15°C outside air temperature:** • Compacted Snow		3	Braking deceleration is noticeably reduced for the wheel braking effort applied OR directional control is noticeably reduced.	Medium	
1/8 inch depth or greater of: • Water • Slush	29-21	2	Braking deceleration OR directional control is between Fair (Medium) and Poor.	Medium to Poor	Poor
• Ice		1	Braking deceleration is significantly reduced for the wheel braking effort applied OR directional control is significantly reduced.	Poor	
• Wet Ice • Water on top of Compacted Snow • Dry Snow or Wet Snow over Ice	20 or lower	0	Braking deceleration is minimal to non-existent for the wheel braking effort applied OR directional control is uncertain.	Nil	Landing not allowed

Figure 2. Runway condition assessment matrix guidance from FAA (Source: Envoy Air).

The company's aircraft operations manual stated that a runway would be considered to be contaminated when more than 25% of the required field length is covered by more than 1/8 inch of standing water, slush, or wet snow. A runway would also be considered to be

contaminated with more than 3/4 inch of dry snow, any compacted snow, or any ice. Further, the manual stated that the maximum crosswind during landing was 30 knots, and that the maximum landing tailwind component was 10 knots.

In addition, the manual stated the following:

> *Braking on a slippery runway can range from fairly good to virtually nil. Snow covered runways are at least twice as slippery as a dry runway….*
>
> *On slippery runways, reversing is the best aid in stopping. Using high levels of symmetrical reverse early in the landing roll will produce the greatest degree of stopping force. When coming out of reverse do not rapidly go from full reverse to forward thrust and thereby increase forward thrust and the stopping problem. Directional control will be primarily through use of the rudder. At lower speeds Nose Wheel Steering and differential braking will, to a degree, provide directional steering.*

The captain reported that he was trained that rudder effectiveness would be reduced with reverse thrust. He also reported being trained to land on a contaminated runway by applying the brakes evenly with "constant and continuous pressure" while maintaining the airplane on the centerline and using maximum reverse until the airplane decelerated to an airspeed of about 80 knots and then as needed.

Administrative Information

Investigator In Charge (IIC):	Ward, Effie Lorenda
Additional Participating Persons:	Edward Delehant; Envoy Patrick Lusch; FAA Paulo M Ribeiro; Embraer Chris Heck; ALPA CENIPA Brazil ; CENIPA
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Note:	The NTSB did not travel to the scene of this accident.
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