Accounting for the Progressive Decrease in Runway Friction Associated with Increasing Rainfall Intensity

Introduction

The National Transportation Safety Board (NTSB) is providing the following information to urge the Federal Aviation Administration (FAA) to take action on the safety recommendations in this report. These recommendations are derived from our investigations of 11 runway overrun accidents and incidents from a 15-year period, 2008–2022, that occurred after the airplanes involved landed on wet runways.[1] The NTSB is issuing three safety recommendations to the FAA.

Background and Analysis

The braking force provided by an airplane's tires is a fundamental factor affecting the runway length required to bring an airplane to a stop after landing. The wheel braking friction coefficient is defined as the horizontal braking force provided by the airplane's tires divided by the vertical force (weight) supported by the tires. The braking force depends on the friction level the runway can provide (the runway's slipperiness), and the vertical force depends on the difference between the weight of the airplane and the lift provided by the airplane's wings. The wheel braking friction coefficient is, therefore, a measure of the slipperiness of the runway. The NTSB developed our technique for using recorded flight data to calculate the wheel braking friction coefficient achieved during a landing following an overrun accident that occurred in Owatonna, Minnesota, on July 31, 2008, when an airplane crashed while attempting to go around after landing on a wet runway.[2] Our review of the airplane stopping performance in the Owatonna accident and in 10 other subsequent

[1] (a) See appendix A for a list of these investigations. (b) Visit ntsb.gov to find additional information in the public dockets for these NTSB investigations (see also case number DCA25SR002). Use the CAROL Query to search safety recommendations and investigations.

[2] NTSB case number DCA08MA085.

overrun events indicates that, in all but 1 of those events, the wheel braking friction coefficient achieved during the landing was substantially less than the wheel braking friction coefficient corresponding to a wet runway specified in the FAA's runway condition assessment matrix (RCAM).[3]

In 9 of the 11 overruns analyzed for this report, the shortfall in the wheel braking friction coefficient most likely resulted from the moderate to heavy rainfall intensities and the associated increased water depths on the runways at the times of the events.[4] Low runway friction was cited as a causal or contributing factor in 8 of the 11 overruns. For example, the NTSB determined that the probable cause of the 2019 runway overrun of the Boeing 737 in Jacksonville, Florida, was, in part, "an extreme loss of braking friction due to heavy rain and the water depth on the ungrooved runway, which resulted in viscous hydroplaning."[5] In all of the overruns, operational errors, such as landing beyond the target touchdown zone, excessive speed, or delayed use of deceleration devices, were also cited as causal or contributing factors.[6]

Additionally, in six of the overruns that occurred while it was raining, the rainfall intensity was 1.3 to 20 times higher than the threshold value for heavy rain, which is 0.30 inches per hour. Heavy rain is the most severe rainfall descriptor currently available in aviation weather reports; such a descriptor is insufficient to identify rainfall intensities that can be many times the threshold value of 0.30 inches per hour. Very high rainfall rates can decrease the wheel braking friction coefficient and significantly increase the required landing distance. For example, in the 2019 Jacksonville, Florida, accident, the rainfall intensities occurring about the time of the landing were 2 to 8 times the heavy rain threshold value. However, for all the overruns considered in this report, the flight crews did not have any information to

---

[3] (a) See the RCAM in appendix B, which is taken from FAA Advisory Circular (AC) 25-32, "Landing Performance Data for Time-of-Arrival Landing Performance Assessments," issued December 22, 2015, where it is titled "Runway Surface Condition–Pilot-Reported Braking Action–Wheel Braking Coefficient Correlation Matrix." This version of the RCAM is intended for providers of landing distance data, such as airplane manufacturers; it includes a wheel braking coefficient column that does not appear in versions of the RCAM presented in other FAA ACs intended for different audiences, such as airport operators. (b) For an overview of the RCAM, see also FAA AC 150/5200-30D, "Airport Field Condition Assessments and Winter Operations Safety," issued October 29, 2020.

[4] One of the overruns analyzed for this report occurred on a runway contaminated with slush.

[5] NTSB. 2021. *Aviation Investigation Final Report*, Jacksonville, Florida, May 3, 2019, case number DCA19MA143.

[6] Deceleration devices include wheel brakes, wing spoilers, and thrust reversers.

prompt them to evaluate the landing distance required using an RCAM runway condition worse than wet. Consequently, landing distances on wet runways calculated using the RCAM can underpredict the actual landing distances required, thereby increasing the risk of a runway overrun.

FAA Advisory Circular (AC) 91-79B, "Aircraft Landing Performance and Runway Excursion Mitigation," recommends that flight crews perform a landing distance assessment prior to landing "when the landing runway is not the same runway analyzed for dispatch or when runway conditions and/or type and depth of contamination [on the runway] have changed [since dispatch]."[7] Runway contaminants decrease the friction capabilities of the runway (thereby increasing the required landing distance), and include liquid rainwater and various forms of frozen precipitation (slush, snow, and ice). Airport operators and flight crews communicate runway conditions using the RCAM.

The RCAM promotes the use of consistent terminology for runway surface conditions among data providers and FAA personnel. The FAA officially started reporting runway conditions for Title 14 *Code of Federal Regulations* (*CFR*) Part 139 airports using the RCAM in October 2016.[8] Specifically, the RCAM provides runway condition codes that correspond to runway contaminant types and depths, pilot braking action reports, and wheel braking friction coefficient values. The runway condition codes range from 6 for a dry runway, to 0 for a runway contaminated with various forms of wet ice, and on which, braking action is minimal to nonexistent. Airplane manufacturers provide flight manual data that flight crews and dispatchers can use to calculate landing distances for runway condition codes 6 through 1. The RCAM states that airplanes should not be operated on runways with condition code 0.

The following three runway condition codes and their corresponding wheel braking friction coefficient models are relevant to wet runways:[9]

[7] AC 91-79B was issued on August 28, 2023; see page 3-1.

[8] (a) A *Part 139 airport* is an airport that, per 14 *CFR* Part 139, requires an FAA operating certificate because it serves scheduled and unscheduled air carrier aircraft with more than 30 seats, or it serves scheduled air carrier operations in aircraft with more than 9 seats but less than 31 seats. For more information see the FAA's web page, "What is Part 139? – Part 139 Airport Certification." (b) See AC 150/5200-30D for a general discussion of the RCAM.

[9] See appendix B for more detailed information.

- **Runway condition code 5** is associated with a pilot-reported braking action of "good" and includes a runway surface that is wet, ranging from damp to having 1/8-inch (3-millimeter [mm]) depth or less of water present. For a runway condition coded as 5, the wheel braking friction coefficient is determined by using the method defined at 14 *CFR* 25.109(c).[10] However, as acknowledged in AC 91-79B, using this method can result in calculated wet-runway landing distances that are too short because the wheel braking friction coefficient underlying the calculations is too high.[11]
- **Runway condition code 3** is associated with a pilot-reported braking action of "medium" and includes a runway surface that is "slippery when wet." The wheel braking friction coefficient for this condition is modeled as a constant 0.16. A "slippery when wet" runway is defined in section 1.12.20 of AC 150/5200-30D, "Airport Field Condition Assessments and Winter Operations Safety," and it is used when the friction level of the runway measured with continuous friction measuring equipment falls below minimum criteria specified in the AC.
- **Runway condition code 2** is associated with a pilot-reported braking action of "medium to poor" and includes a runway surface that is flooded, which means the runway has greater than 1/8 inch (3 mm) of water present and dynamic hydroplaning is possible. For airplane groundspeeds at and above 85% of the hydroplaning speed, the wheel braking friction coefficient is modeled as a constant 0.05. Below 85% of the hydroplaning speed, the wheel braking friction coefficient is modeled as 50% of the wheel braking coefficient determined in accordance with 14 *CFR* 25.109(c), but no greater than 0.16.

[10] Title 14 *CFR* 25.109 addresses the accelerate-stop distance for transport-category airplanes, and it defines the wheel braking friction coefficient on a smooth (non-grooved) wet runway as the maximum wheel braking friction coefficient that can be achieved on the runway multiplied by the efficiency of the anti-skid braking system of the airplane (assumed to be 80% for modern anti-skid systems). The maximum wheel braking friction coefficient is defined in terms of the airplane's ground speed and tire inflation pressure. The maximum wheel braking friction coefficient decreases with ground speed at a given tire pressure, and it decreases with higher inflation pressure at a given ground speed. For example, the maximum wheel braking friction coefficient for an airplane with a tire inflation pressure of 200 pounds per square inch is 0.17 at a ground speed of 120 knots, and it is 0.30 at a ground speed of 60 knots.

[11] See page 3-4 of AC 91-79B.

AC 150/5200-30D states the following:

> To use the RCAM, the airport operator will use the same runway condition assessment practices as they have used in the past. The airport operator will assess surfaces, report contaminants present, and the Notice to Airmen (NOTAM) system (NOTAM Manager or ENII [e-NOTAM version II]) will generate the [runway condition codes] based on the RCAM when applicable.[12]

AC 150/5200-30D also notes that the runway condition codes generated using the RCAM based on the assessment of contaminants on the runway might have to be "downgrade[d]" because "a more slippery condition than is generated by the RCAM" exists.[13] This determination is based on "other observations related to runway slipperiness," including pilot braking action reports.[14] Consequently, the NOTAM system normally generates runway condition codes based on the airport operator's assessment of runway contaminants; however, the operator can downgrade (lower) the runway condition code to represent a more slippery runway based on braking action reports received from landing flight crews.

Without a braking action report from a preceding airplane flight crew, airport operators and pilots using the RCAM in wet conditions will likely assume a runway condition code of 5 by default, because in practice water depths on runways are generally not measured and many airports that support turbine airplane traffic do not have a continuous friction measuring equipment program.[15]

Braking action reports can be communicated to the flight crews of landing airplanes by the local air traffic control tower. If the airport is not served by an air traffic control tower, or if there is no preceding airplane flight crew to provide a timely braking action report, then there is no mechanism, other than a pilot's personal judgment based on the environmental conditions, for assigning a runway condition

[12] See page 5-14 of AC 150/5200-30D.

[13] See pages 5-15 and 5-16 of AC 150/5200-30D.

[14] See page 5-16 of AC 150/5200-30D.

[15] (a) Runway condition code 2 corresponds to a runway flooded with 1/8 inch (3 mm) of water, but if the water depth is not measured, then there is no way to determine that the runway is flooded and should be assigned runway condition code 2. (b) Because of the resources required, in general only larger Part 139 airports maintain a continuous friction measuring equipment program. However, without this equipment, runways cannot be designated "slippery when wet" (corresponding to RCAM runway condition code 3).

code less than 5 to a wet runway. There is an exception for certain Part 139 airports that might have identified some runways as "slippery when wet" based on continuous friction measuring equipment measurements. As noted above, airplane manufacturers provide flight manual data that can be used to calculate landing distances for runway condition codes 6 through 1. Also, AC 91-79B encourages pilots to make a time-of-arrival landing distance assessment using the expected conditions on the runway. However, the current implementation of the RCAM results in pilots assuming a runway condition code of 5 for the vast majority of wet runways, particularly if there is no preceding flight crew providing a braking action report, and limits access to the lower runway condition codes specified in the RCAM that are more representative of the true friction capabilities of wet runways at higher rainfall intensities. For all of the overruns considered in this report, the flight crews did not have any information to prompt them to evaluate the landing distance required using an RCAM runway condition worse than wet. Therefore, the appropriate runway condition code for these events, from an operator's point of view, was code 5, even though lower runway condition codes would have been more representative of the true friction capabilities of the runways.

The method described in 14 *CFR* 25.109(c) for determining the wheel braking friction coefficient corresponding to RCAM runway condition code 5 accounts for the airplane's ground speed and tire pressure. However, the maximum wheel braking friction coefficient on a wet runway is affected by additional factors not considered in 14 *CFR* 25.109(c), including water depth on the runway, runway surface material and texture, rubber deposits on the runway, tire wear, and runway temperature.

The NTSB's investigations of 11 wet-runway overrun events between 2008 and 2022 showed that the actual wheel braking friction coefficient attained in all but 1 event was less than that predicted by using the method defined at 14 *CFR* 25.109(c) for runway condition code 5. Consequently, the actual landing distance required was longer than that calculated by assuming a runway condition code of 5. Therefore, the NTSB concludes that the wheel braking friction coefficient corresponding to a wet runway can be substantially less than that specified by RCAM runway condition code 5 at 14 *CFR* 25.109(c) due to limitations in the factors considered in the regulation, and therefore, wet-runway landing distances calculated using this wheel braking friction coefficient can underestimate the actual landing distances required and increase the risk of a runway overrun.

As noted, the method defined at 14 *CFR* 25.109(c) does not consider how water depth affects the maximum wheel braking friction coefficient. Although the RCAM recognizes the significance of water depth as it relates to the potential for dynamic hydroplaning by assigning runway condition code 2 to runways contaminated with greater than 1/8-inch (3-mm) depth of water or slush, it does not account for the fact that the maximum wheel braking friction coefficient decreases progressively with water depth even at depths below 3 mm.[16] Currently, the RCAM accounts for the decrease in the maximum wheel braking friction coefficient with an increase in water depth as a sudden discontinuous shift from a runway condition code of 5 to a code of 2, once the water depth exceeds 3 mm. However, this discontinuity is not real because just as the water depth increases progressively with increasing rainfall intensity, the maximum wheel braking friction coefficient decreases progressively with water depth. Thus, the maximum wheel braking friction coefficient on a wet runway decreases progressively as rainfall intensity increases. The NTSB concludes that the RCAM would better represent the behavior of the maximum wheel braking friction coefficient on wet runways if progressively higher rainfall intensities corresponded to progressively lower runway condition codes. Therefore, the NTSB recommends that the FAA update the RCAM runway condition codes assigned to wet runways to account for the progressive decrease in the wheel braking friction coefficient associated with increasing rainfall intensity.

The depth of water on a runway increases with rainfall intensity, but it is also dependent on the macrotexture of the runway surface. The runway macrotexture depth is the average depth of irregularities in the surface of the runway, produced by the coarseness of the surface texture. The greater the number and magnitude of these irregularities, the more channels are provided for water to flow through, and the higher the rainfall intensity required to submerge the peaks of the irregularities. On a grooved runway, mechanically created grooves provide additional macrotexture to facilitate this drainage and increase the rainfall intensity the runway can accept before the water depth rises above the peaks. Consequently, at a given rainfall intensity, the water depth on a grooved runway will be less than that on a smooth runway, and the maximum wheel braking friction coefficient will be correspondingly higher. The update to the RCAM proposed in Safety Recommendation A-26-61 should account for this difference between smooth and grooved runways, and one possible method of doing so is proposed on page 11 of this report.

[16] For a detailed discussion of the factors affecting the wheel braking friction coefficient on a wet runway, including water depth, in the context of the NTSB investigations analyzed for this report, see O'Callaghan, John J. 2023. "Wet-Runway Overruns: Still a Slippery Problem." Presented at the 2023 International Society of Air Safety Investigators (ISASI) Seminar in Nashville, Tennessee. (The paper is available via the ISASI website and in the public docket for this NTSB report (case number DCA25SR002).

The importance of rainfall intensity was explicitly recognized in FAA's Safety Alert for Operators (SAFO) 19003, "Turbojet Braking Performance on Wet Runways," as follows:

> Rainfall intensity may be the only indication available to the pilot that the water depth present on the runway may be excessive. The 1/8-inch threshold that separates a wet runway with a [runway condition code] of 5 from [a] runway contaminated with [a] water depth greater than 1/8-inch (a [runway condition code] of 2) is based on [the] possibility of dynamic hydroplaning.[17]

AC 91-79B also recognizes the risks associated with moderate or heavy rain and the concern with RCAM runway condition code 5, stating the following:[18]

> **ATTENTION**: Pilots are strongly advised to review the weather conditions and compare that to the time of the latest braking action report. . . .
>
> **Risks Associated with Moderate or Heavy Rain.** Several runway excursions and overruns have raised concerns with wet runway stopping performance assumptions. Analysis of the stopping data from these incidents and accidents indicates the braking coefficient in each case was significantly lower than expected for a wet runway than would be predicted by [14 *CFR*] 25.109 and AC 25-7[D]. . . .[19]
>
> [Runway Condition Code] Limitations. Note on the RCAM . . . that only 1/8 inch of water separates a wet runway (with a [runway condition code] of 5 and "good" braking action) from a runway contaminated with standing water (and a [runway condition code] of 2 and "medium to poor" braking action). This dramatic difference is due to the possibility of dynamic hydroplaning that may occur any time water depth exceeds 1/8 inch.

[17] SAFO 19003 was issued on July 2, 2019, and it was canceled on August 28, 2023, with the issuance of AC 91-79B. See pages 1 and 2 of SAFO 19003.

[18] These excerpts are taken from pages 3-4 and 3-5 of AC 91-79B.

[19] FAA AC 25-7D, "Flight Test Guide for Certification of Transport Category Airplanes," was issued on September 16, 2025.

AC 91-79B emphasizes the importance of a pilot's role in observing heavy rain and recognizing the potentially adverse effect of heavy rain on braking performance during wet runway landings, which may necessitate longer landing distances than those prescribed by regulations and standard operating procedures. Accordingly, flight crews could be better prepared to anticipate slippery conditions and corresponding longer landing distances if the rainfall intensity descriptors provided in aviation weather reports (and transmitted to flight crews) were more detailed and identified rainfall intensities that can be many multiples of the current 0.30 inches per hour threshold that defines heavy rain (see table 1 below). Further, such rainfall intensity descriptors could also be used to inform the assignment of more accurate RCAM runway condition codes that reflect the progressive decrease in the wheel braking friction coefficient as water depths increase with rainfall intensity.

The rainfall intensity descriptors used in aviation weather reports in the United States are defined in the *Federal Meteorological Handbook No. 1: Surface Weather Observations and Reports*. See table 1 below:[20]

Table 1. Intensity of rain or ice pellets, rate-of-fall criteria, and estimation criteria. (Source: *Federal Meteorological Handbook No. 1: Surface Weather Observations and Reports*.)

Intensity	Rate-of-Fall Criteria	Estimation Criteria
Light	Up to 0.10 inches per hour; maximum 0.01 inches in 6 minutes.	From scattered drops that, regardless of duration, do not completely wet an exposed surface up to a condition where individual drops are easily seen.
Moderate	0.11 inches to 0.30 inches per hour; more than 0.01 inches to 0.03 inches in 6 minutes.	Individual drops are not clearly identifiable; spray is observable just above pavements and other hard surfaces.
Heavy	More than 0.30 inches per hour; more than 0.03 inches in 6 minutes.	Rain seemingly falls in sheets; individual drops are not identifiable; heavy spray to height of several inches is observed over hard surfaces.

Note, in table 1, that heavy rain, the most intense rainfall rate descriptor available, corresponds to rainfall rates greater than 0.30 inches per hour. However, in six of the overruns analyzed for this report, the NTSB found that the rainfall intensity was 1.3 to 20 times higher than the threshold value for heavy rain.[21] For example, the NTSB found that the rainfall rates occurring about the time of the 2019 Boeing 737

[20] (a) National Oceanic and Atmospheric Administration. 2019. *Federal Meteorological Handbook No. 1: Surface Weather Observations and Reports*. FCM-H1-2019. Washington, DC.
(b) Table 1 in this report is adapted from tables 8-1 and 8-2 in the *Federal Meteorological Handbook No. 1*: *Surface Weather Observations and Reports*.

[21] These include NTSB case numbers DCA10RA017, DCA11IA047, CEN16FA286, DCA19IA036, DCA19MA143, and ERA21LA353.

landing overrun accident in Jacksonville, Florida, were 0.6 to 2.4 inches per hour, or 2 to 8 times the heavy rain threshold.[22] Further, the NTSB found that the rainfall rates at the time of the 2016 Embraer 505 landing overrun accident in Sugar Land, Texas, were 4.2 to 6.0 inches per hour, or 14 to 20 times the heavy rain threshold.[23] These two examples show that the heavy rain descriptor cannot distinguish the substantial difference between potential rainfall rates of 2.4 inches to 6.0 inches per hour (8 to 20 times the heavy rain threshold) and 0.3 inches per hour (the threshold itself). The water depth on a runway and the resulting maximum wheel braking friction coefficient can vary considerably over this range of rainfall intensities. Consequently, a report of heavy rain might not communicate to flight crews the true intensity of the rainfall at an airport, thereby, impairing their ability to accurately assess the runway conditions and the required landing distance. The NTSB concludes that the rainfall intensity descriptors currently used in aviation weather reports do not identify the highest rainfall intensities that are possible at an airport, and therefore, these descriptors limit the ability of flight crews to accurately assess the runway condition and the required landing distance when such rainfall intensities are present.

Further, in extreme rainfall conditions, such as those surrounding the 2019 Jacksonville and 2016 Sugar Land accidents, the maximum wheel braking friction coefficient can be reduced to such an extent that pilots should not attempt to land at all. Avoiding landings in dangerous rainfall conditions without unnecessarily disrupting operations will require identifying and communicating the presence of such conditions to flight crews. This in turn will require new rainfall intensity descriptors that identify rainfall rates that can be several multiples of the current heavy rain threshold, which will then require updating the RCAM to incorporate these descriptors. Therefore, the NTSB recommends that the FAA add additional rainfall intensity descriptors to be used in aviation weather reports to identify rainfall intensities that can substantially exceed the current heavy rain threshold of 0.3 inches per hour.

A broader range of rainfall rates using additional rainfall intensity descriptors (such as, "heavy +" or "heavy ++") could help inform the assignment of lower RCAM runway condition codes when the rainfall intensity at an airport exceeds prescribed thresholds. An example of how such additional rainfall intensity descriptors could be incorporated in the RCAM is provided in table 2.

[22] NTSB case number DCA19MA143.

[23] NTSB case number CEN16FA286.

Table 2. Example of possible modification of the RCAM to account for additional rainfall intensity descriptors and the decreased wheel braking friction coefficients associated with correspondingly lower runway condition codes (for illustrative purposes only).

Rainfall Intensity (*I*), inches per hour	Descriptor	Runway Condition Code
$0 < I \leq 0.1$	Light	5
$0.1 < I \leq 0.3$	Moderate	4
$0.3 < I \leq 0.5$	Heavy	3
$0.5 < I \leq 1.0$	Heavy +	2
$1.0 < I \leq 2.0$	Heavy ++	1
$2.0 < I$	Heavy +++	0

As noted on page 7 of this report, at a given rainfall intensity, runway grooving results in additional water drainage paths and decreased water depth above the runway surface irregularities. Runway grooving could be accounted for in the RCAM modifications suggested in table 2 by decreasing the rainfall intensity used in the table. Specifically, when the runway is grooved, the rainfall intensity used to look up the runway condition code in table 2 could be reduced by a prescribed amount to account for the additional water drainage provided by the runway grooves.

The NTSB concludes that a broader range of available rainfall intensity descriptors would help to more accurately associate progressively higher rainfall intensities with progressively lower runway condition codes in the RCAM. Therefore, the NTSB further recommends that once the rainfall intensity descriptors used in aviation weather reports are updated as recommended in Safety Recommendation A-26-62, the FAA incorporate these descriptors in the RCAM.

Conclusions

Findings

1. The wheel braking friction coefficient corresponding to a wet runway can be substantially less than that specified by runway condition assessment matrix (RCAM) runway condition code 5 at Title 14 *Code of Federal Regulations* 25.109(c) due to limitations in the factors considered in the regulation, and therefore, wet-runway landing distances calculated using this wheel braking friction coefficient can underestimate the actual landing distances required and increase the risk of a runway overrun.

2. The runway condition assessment matrix would better represent the behavior of the maximum wheel braking friction coefficient on wet runways if progressively higher rainfall intensities corresponded to progressively lower runway condition codes.

3. The rainfall intensity descriptors currently used in aviation weather reports do not identify the highest rainfall intensities that are possible at an airport, and therefore, these descriptors limit the ability of flight crews to accurately assess the runway condition and the required landing distance when such rainfall intensities are present.

4. A broader range of available rainfall intensity descriptors would help to more accurately associate progressively higher rainfall intensities with progressively lower runway condition codes in the runway condition assessment matrix.

Recommendations

New Recommendations

To the Federal Aviation Administration:

Update the runway condition assessment matrix (RCAM) runway condition codes assigned to wet runways to account for the progressive decrease in the wheel braking friction coefficient associated with increasing rainfall intensity. (A-26-61)

Add additional rainfall intensity descriptors to be used in aviation weather reports to identify rainfall intensities that can substantially exceed the current heavy rain threshold of 0.3 inches per hour. (A-26-62)

Once the rainfall intensity descriptors used in aviation weather reports are updated as recommended in Safety Recommendation A-26-62, incorporate these descriptors in the runway condition assessment matrix (RCAM). (A-26-63)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JENNIFER L. HOMENDY
Chairwoman

THOMAS CHAPMAN
Member

MICHAEL E. GRAHAM
Vice Chairman

JOHN DELEEUW
Member

Report Date: May 12, 2026

Appendixes

Appendix A: Wet-Runway Overrun Events Analyzed for This Report

See table A-1 for a list of the 11 wet-runway overrun events analyzed for this report. More information about these runway overrun events is available in the final reports and airplane performance studies in the dockets for these investigations, which are available via NTSB's CAROL Query.

Table A-1. Wet-runway overrun events analyzed for this report, 2008–2022.

NTSB or Foreign Agency Case Number	Date	Location (Runway)	Rainfall Descriptor	Rainfall Intensity (inches per hour)	Airplane Model
DCA08MA085	7/31/2008	Owatonna, MN (KOWA 30)	Moderate	0.27	BAe 125-800A
DCA10RA017 / JCAA JA-2009-09	12/22/2009	Kingston, Jamaica (MKJP 12)	Heavy	0.49	B737-800
DCA10RA069 / TSB A10H004	6/16/2010	Ottawa, Ontario, Canada (CYOW 07)	Heavy	0.31	EMB-145
DCA11IA047	4/26/2011	Chicago, IL (KMDW 13C)	Heavy	0.60	B737-700
CEN14FA505	9/19/2014	Conroe, TX (KCXO 1)	Moderate to heavy	0.24–0.30+	EMB-505
CEN15LA057	11/21/2014	Sugar Land, TX (KSGR 35)	Moderate	0.12	EMB-500
CEN16FA286	7/26/2016	Sugar Land, TX (KSGR 35)	Heavy	4.2–6.0	EMB-505
DCA19IA036	12/06/2018	Burbank, CA (KBUR 8)	Heavy	1.00	B737-700
DCA19MA143	5/03/2019	Jacksonville, FL (KNIP 10)	Heavy	0.60–2.40	B737-800
ERA21LA353	8/26/2021	Banner Elk, NC (NC06 12)	Moderate to heavy	0.20–0.40	EMB-505
ERA22LA150	3/09/2022	Pittsburgh, PA (KAGC 28)	10% 0.125 inch slush[a]	0	HA-420

[a] This descriptor means that 10% of the runway surface was covered with 0.125 inches of slush.

The final report concerning the landing overrun accident in Kingston, Jamaica, in 2009 titled *Runway Overrun on Landing, American Airlines, Flight AA331, Boeing 737-823, United States Registration N977AN, Norman Manley International Airport, Kingston, Jamaica (MKJP), December 22, 2009*, (report number JA-2009-09) is available from the Jamaica Civil Aviation Authority. The NTSB participated in but did not lead this investigation (DCA10RA017).

The final report concerning the landing overrun accident in Ottawa, Ontario, Canada, in 2010 titled *Runway Overrun, Trans States Airlines LLC, Embraer EMB-145LR N847HK, Ottawa/MacDonald-Cartier International Airport, Ontario, June 16, 2010*, (report number A10H004) is available from the Transportation Safety Board of Canada. The NTSB participated in but did not lead this investigation (DCA10RA069).

The one event in which the attained wheel braking friction coefficient reached and exceeded the maximum wheel braking friction coefficient defined by 14 *CFR* 25.109(c) is the 2018 overrun that occurred in Burbank, California (DCA19IA036).

Appendix B: RCAM Published in AC 25-32

Table B-1 is adapted from table 2, "Runway Surface Condition—Pilot-Reported Braking Action—Wheel Braking Coefficient Correlation Matrix," in AC 25-32.

Table B-1. RCAM published in AC 25-32.

Runway Condition Code	Runway Surface Condition Description	Pilot-Reported Braking Action	Wheel Braking Coefficient
6	• Dry	—	90% of certified value used to comply with [14 *CFR*] 25.125.[a]
5	• Frost • Wet (includes damp and 1/8″ (3 mm) depth or less of water) 1/8″ (3 mm) depth or less of: • Slush • Dry snow • Wet snow	Good	Per method defined in [14 *CFR*] 25.109(c).
4	-15 °C and colder outside air temperature: • Compacted snow	Good to Medium[b]	0.20[c]
3	• Wet ("Slippery When Wet" runway) • Dry snow or wet snow (any depth) over compacted snow Greater than 1/8″ (3 mm) depth of: • Dry snow • Wet snow Warmer than -15° C outside air temperature: • Compacted snow	Medium[b]	0.16[c]
2	Greater than 1/8″ (3 mm) depth of: • Water • Slush	Medium[b] to Poor	1. For speeds below 85% of the hydroplaning speed.[d] 50% of the wheel braking coefficient determined in accordance with [14 *CFR*] 25.109(c), but no greater than 0.16[c]; and 2. For speeds at 85% of the hydroplaning speed[d] and above: 0.05.[c]
1	• Ice	Poor	0.08[c]
0	• Wet ice • Water on top of compacted snow • Dry snow or wet snow over ice	Nil	Not applicable. (No operations in Nil conditions.)

[a] 100% of the wheel braking coefficient used to comply with [14 *CFR*] 25.125 may be used if the testing from which that braking coefficient was derived was conducted on portions of runways containing operationally representative amounts of rubber contamination and paint stripes.

[b] The braking action term "FAIR" is in the process of being changed to "MEDIUM" throughout the FAA. Until an official change is published, the term "FAIR" should be used.

[c] These wheel braking coefficients assume a fully modulating anti-skid system. For quasi-modulating systems, multiply the listed braking coefficient by 0.625. For on-off systems, multiply the listed braking coefficient by 0.375. (See AC 25-7[D] ["Flight Test Guide for Certification of Transport Category Airplanes," issued September 16, 2025] to determine the classification of an anti-skid system.) Airplanes without anti-skid systems will need to be addressed separately on a case-by-case basis.

[d] The hydroplaning speed, V_P, may be estimated by the equation $V_P = 9\sqrt{P}$, where V_P is the ground speed in knots and P is the tire pressure in [pounds per square inch].

The NTSB is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant events in the other modes of transportation—railroad, transit, highway, marine, pipeline, and commercial space. We determine the probable causes of the accidents and events we investigate and issue safety recommendations aimed at preventing future occurrences. In addition, we conduct transportation safety research studies and offer information and other assistance to family members and survivors for each accident or event we investigate. We also serve as the appellate authority for enforcement actions involving aviation and mariner certificates issued by the Federal Aviation Administration (FAA) and US Coast Guard, and we adjudicate appeals of civil penalty actions taken by the FAA.

The NTSB does not assign fault or blame for an accident or incident; rather, as specified by NTSB regulation, "accident/incident investigations are fact-finding proceedings with no formal issues and no adverse parties … and are not conducted for the purpose of determining the rights or liabilities of any person" (Title 49 *Code of Federal Regulations* section 831.4). Assignment of fault or legal liability is not relevant to the NTSB's statutory mission to improve transportation safety by investigating accidents and incidents and issuing safety recommendations. In addition, statutory language prohibits the admission into evidence or use of any part of an NTSB report related to an accident in a civil action for damages resulting from a matter mentioned in the report (Title 49 *United States Code* section 1154(b)).

For more detailed background information on this report, visit the NTSB Case Analysis and Reporting Online (CAROL) website and search for NTSB accident ID DCA25SR002. Recent publications are available in their entirety on the NTSB website. Other information about available publications also may be obtained from the website or by contacting –

National Transportation Safety Board
Records Management Division, CIO-40
490 L'Enfant Plaza, SW
Washington, DC 20594
(800) 877-6799 or (202) 314-6551