Handling Wet and

The clean aircraft concept **doesn't translate to clean** runways

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Every year or so we see another case of a passenger-carrying airplane sliding off the end of a runway. Given the sheer number of landings in a winter season, I'm surprised it doesn't happen more regularly.

More often than not, pilot error is implicated, prompting the usual call for pilots to stop floating down the runway and get serious about the things that make the airplane stop. We pilots typically and quickly dismiss the actions of the accident crew, rationalizing that they obviously didn't take their jobs seriously enough and that we, just as obviously, do. But when it comes our time to face a wet or contaminated runway, we realize once again the same problems those who came before us faced.

We can fly halfway around the world and our en route time and fuel burn will be within a percentage point of what we had planned. But at the end of that flight, we can be faced with a reported runway condition that seems hardly better than a guess. There are steps we can take to improve our ability to stop. But before we do that, we need to understand the actual condition of the runway.

Before and After Southwest 1248

I flew into Chicago Midway (KMDW) as a passenger aboard a Southwest Airlines flight during the first week of December 2005. As I recall, it was raining, snowing or sleeting and the runway appeared sloppy but probably no worse than a "fair" braking action report for a Boeing 737. From my vantage point in the cabin, the pilots appeared to touch down about 1,500 ft. down the runway. It was a very smooth landing, one that generated some applause in the cabin. I am loathe to criticize pilots from a cabin seat perspective, knowing how hard it is to assess these things anywhere aft of the front two seats on the airplane. What got my attention, however, was the lack of reverse thrust. "Not how I would have done that," I said to myself.

The next week, on Dec. 8, 2005, everything changed for Southwest in particular and for professional pilots in general. On that day Southwest Flight 1248 failed to stop on the slush-covered runway at KMDW. The airplane departed the end of the runway, rolled through a blast fence, a perimeter fence, and on to a roadway. In that excursion, the 737 collided with some vehicles and came to rest on the corner of South Central Avenue and West 55th Street. A six-year-old boy in one of the vehicles

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Assessment Criteria		Control/Braking Assessment Criteria	
Runway Condition Description	RwyCC	Deceleration or Direction Control Observation	Pilot Reported Braking Action
• Dry	6	---	---
• Frost • Wet (includes damp and 1/8 inch depth or less of water) **1/8 Inch (3mm) Depth or Less of:** • Slush • Dry Snow • Wet Snow	5	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
-15°C and Colder Outside Air Temperature: • Compacted Snow	4	Braking deceleration OR directional control is between good and medium.	Good to Medium
• Slippery When Wet (wet runway) • Dry Snow or Wet Snow (any depth) Over Compacted Snow **Greater Than 1/8 Inch (3mm) Depth 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
Greater Than 1/8 Inch (3mm) Depth of: • Water • Slush	2	Braking deceleration OR directional control is between medium and poor.	Medium to Poor
• Ice	1	Braking deceleration is significantly reduced for the wheel braking effort applied OR directional control is significantly reduced.	Poor
• Wet Ice • Slush Over Ice • Water Over Compacted Snow • Dry Snow or Wet Snow Over Ice	0	Braking deceleration is minimal to non-existant for the wheel braking effort applied OR directional control is uncertain.	Nil

The Runway Condition Assessment Matric (Pilot's Version), from AIM

died as a result of injuries sustained in the accident.

Two months later I had another flight into Midway on the same airline. Although the runway was dry, the pilot planted the airplane in the touchdown zone, went to full reverse, and brought us to taxi speed with half the runway remaining. "Better," I said to myself.

The next year, the FAA issued SAFO 06012, advocating a 15% margin between the expected actual airplane landing distance and the landing distance available at the time of arrival. Ten years after that, the agency issued SAFO 16009, implementing a new way of evaluating runway condition. While we still have braking action reports ranging from "good" to "nil" to contend with, our new lexicon includes a Runway Condition Assessment Matrix (RCAM) that generates Runway Condition Codes (RCCs). Those of us who spend hours studying the Aeronautical Information Manual (AIM) have noticed that as the RCAM was added, our old friend mu (μ) was deleted. In fact, airport operators are no longer allowed to give pilots an mu reading, even if they have them. It seems we have traded a scientific number (two digits and a decimal!), for a set of three numbers from zero to six. How can a 3/3/3 be better than a 0.30? As it turns out, you cannot really understand an RCC until you understand mu.

So, What's Mu (μ), Anyway?

Time for some basic engineering: $F_f = \mu F_n$, where F_f is the friction force in newtons, μ is the coefficient of friction, and F_n is the normal force in newtons. A newton is the International System of Units (SI) derived unit of force. One newton is equal to the force needed to accelerate a mass of 1 kg 1 meter per second per second. How about all this in plain English?

Imagine trying to push a heavy object along a floor. F_n is the weight of the object pushing down on the floor. F_f is the force needed to push it. Mu (μ) is the resistance of the two surfaces sliding against each other. If the surface is very "grippy" and will not allow the object to slide, it might have a coefficient of friction of 1.0 — meaning it would take just as much force to lift the object as it would to push it. If the surface is extremely slippery, it could theoretically have a coefficient of 0.0 — meaning it takes no effort at all to push the object. The coefficient of friction can be greater than 1.0. (Imagine the object Velcroed to the surface, for example.)

So, it seems mu is a very scientific and precise number after all, in theory. In practice, however, the mu of a runway surface is very hard to measure. There are a variety of decelerometers and vehicles designed for the task, but these tend to depend on operator proficiency to get it just right. Some runway contaminants do not yield consistent mu results, even with an expert running the measuring equipment. As if all this wasn't bad enough, we can add variations in nomenclature to the problem.

Wet, Icy, Contaminated and Even 'Damp'

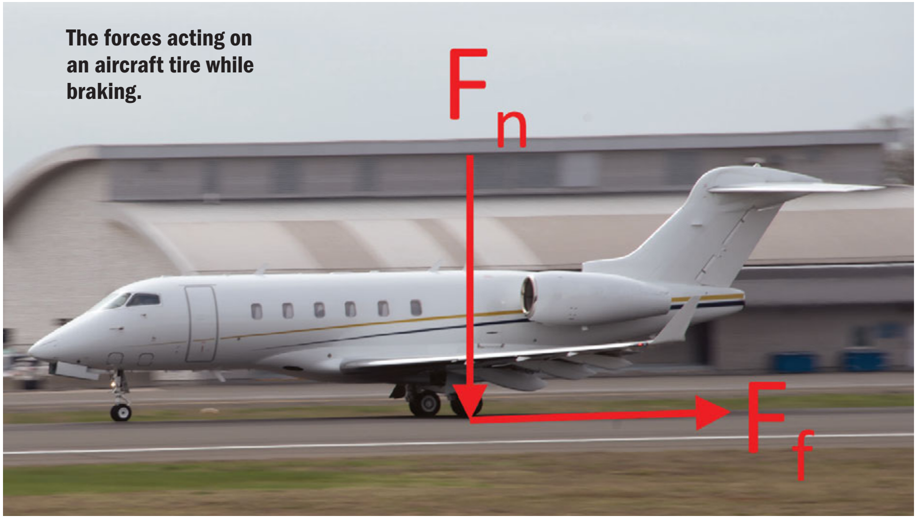
U.S. pilots can get the definition of runway contamination in the AIM and for a wet runway in Advisory Circular (AC) 91-79A. Airport operators are given more information in AC 150/5200-30D. U.S. rules tend to lag the International Civil Aviation Organization (ICAO), which offers definitions in Annex 6, Part 1, Attachment B. The EU seems to have the strictest definitions, given in European Aviation Safety Agency Air Ops Annex 1. I think it is helpful to know the most restrictive rules if you fly all over the world. Things get complicated by aircraft manufacturers, but this is a way to begin getting a handle on all this.

▶ A runway is dry if it is free of visible moisture.

▶ A runway is "effectively dry" if it is grooved or if it is a specially prepared porous pavement maintained to retain dry braking action even when moisture is present.

▶ A runway is damp if there is a moisture layer that is not shiny.

▶ A runway is wet if there is enough moisture on the runway surface to cause it to be reflective but without significant areas of standing water, or if it is covered in water (or the equivalent) and no more than 25% of that is no more than



The forces acting on an aircraft tire while braking.

0.125 in. (3 mm) of water or the equivalent in slush or loose snow.

▶ A runway is contaminated if more than 25% of it is covered by more than 0.125 in. (3 mm) water or the equivalent in slush or loose snow, or if more than 25% of it is covered in compressed or compacted snow, ice or wet ice.

Some of these definitions can be negated by your aircraft manufacturer. Not all manufacturers, for example, consider a wet grooved runway to be "effectively dry."

Braking Action Reports

The AIM notes that "ATC furnishes pilots the quality of braking action received from pilots." It is important to realize that braking action reports are exchanged between pilots and ATC, and that the airport operator is not involved. The quality of braking action is described by the terms "good," "good to medium," "medium," "medium to poor," "poor" and "nil." When tower controllers receive runway braking action reports that include the terms medium, poor or nil, or whenever weather conditions are conducive to deteriorating or rapidly changing runway braking conditions, the tower will include on the ATIS broadcast the statement, "Braking action advisories are in effect."

Of course, pilot braking action reports are highly subjective. Generally speaking, lighter aircraft may have more difficulty stopping than heavier aircraft with larger tires and brakes. SAFO 06012 goes further to say the pilots of two identical aircraft landing in the same conditions, on the same runway could give different braking action reports. These differing reports could be the result of differences between the specific aircraft, aircraft weight, pilot technique, pilot experience in similar conditions, pilot total experience and pilot expectations.

Also, runway surface conditions can degrade or improve significantly in very short periods of time dependent on precipitation, temperature, usage and runway treatment. While braking action reports offer "news" of what we can expect, they do not help us convert the dry runway stopping distances in our aircraft manuals into reliable numbers for conditions less than dry.

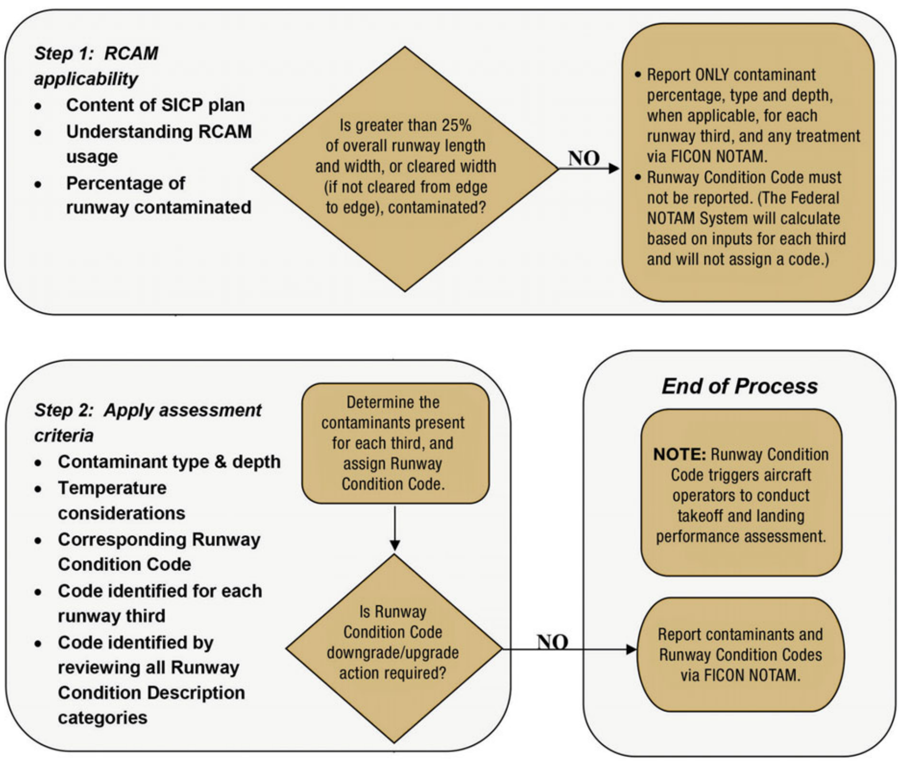
Runway Condition Codes (RCCs)

As hard as we've tried over the years, we can't seem to come up with a definitive way of translating the condition of a runway into a number that we can plug into tables and charts to figure out our likelihood of stopping the airplane in the amount of runway in front of us. Some aircraft manufacturers are offering software applications that will do just that, turning a Runway Condition Code (RCC) into very precise takeoff and landing distances.

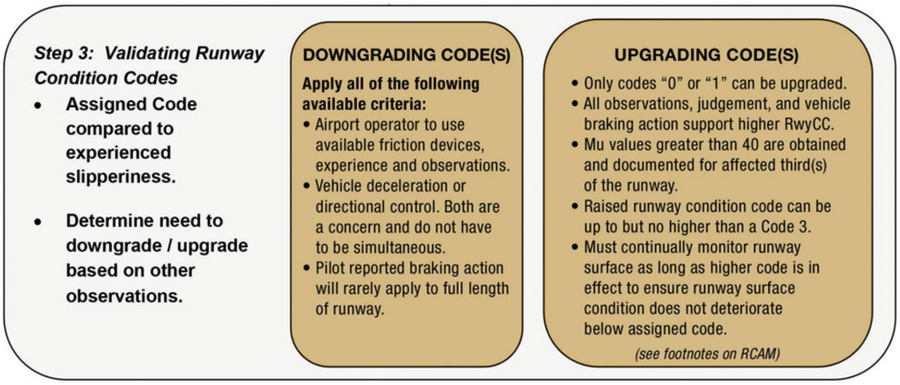
A critical eye, however, reveals problems with the subjective nature of determining an RCC. Ice, for example, appears to generate an RCC of 1, no matter the thickness or roughness of the covering. A half an inch of dry snow gives us a 3, but so does a foot of dry snow.

LGA RWY 13 FICON 1/1/1 100 PRCT ICE OBSERVED AT 1701040230.

To really understand what a FICON (Field Condition Report) Notice to Airmen (NOTAM) is trying to say about a runway, pilots should understand that an RCC is a product of the airport



RCAM Process, Steps 1 & 2, from AC 150/5200-30D



RCAM Process, Step 3, from AC 150/5200-30D

operator, not ATC. An RCC can result from a member of airport management simply looking out the window and observing conditions, or be elaborately produced by taking several passes with a vehicle equipped with a decelerometer to obtain mu readings. No matter how the assessment is made, it must then be entered into the NOTAM system in which the airport operator has very little flexibility. The process is given in AC 150/5200-30D, a document intended for airport managers but invaluable to pilots trying to understand the RCAM process.

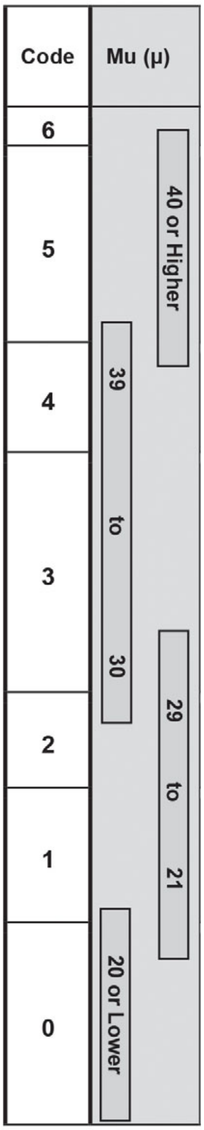
Airport operators normally access the system through a web-based application called the "NOTAM Manager." The first question posed to be answered: "Is greater than 25% of the overall runway length and width, or cleared width (if not cleared from edge to edge), contaminated?" If the answer is no, the only option will be to report contaminant percentage, type and depth, when applicable, for each third of the runway, as well as any treatment. In this example, an RCC will not be reported.

With more than 25% coverage, the next thing to do is go to the left column on the RCAM and look for the type and depth of contaminant as well as temperature, and then repeat that for each third of the runway. If only a portion of the runway is cleared (such as the center 75 ft.), you only have to consider that portion. At this point, the NOTAM Manager automatically generates RCCs. Note that no decelerometer mu readings were needed to generate the RCC.

If the airport operator thinks the RCC can be upgraded or should be downgraded, he can take a drive with an approved decelerometer. The RCAM has an additional column of mu readings used to adjust RCCs. But only RCCs of 1 or 2 can be upgraded and even then, they can only be upgraded to a 3. You can also use the decelerometer's mu reading to downgrade the RCC.

What about pilot reports? These can only be used to downgrade an RCC and only for the portion of the runway the reporting pilots had experienced. An RCC cannot be upgraded as a result of a pilot braking action report. Two winters ago, I was frustrated one morning when our airport, Hanscom Field, Bedford, Massachusetts (KBED), reported an RCC of 1/1/1 with ice covering the entire runway. I drove out to the runway in an airport operations truck and stood on the ice, which appeared to be thin, covering about a quarter inch of standing water. My feet broke right through and the soles of my shoes gripped tightly to the pavement. The operations driver explained that the airport could upgrade the 1/1/1 to no higher than a 3/3/3, but only if the mu gave us a 40 or higher. We ran the truck up to 20 mi. per hour and stepped on the brakes (as required by the decelerometer instructions). Our highest mu was 35.

"A 40 is dry," the driver explained, "and 35 is pretty close. But the rules say 40." About an hour later, just as the sun came up, a Gulfstream landed and reported "braking action good." For a brief moment the airport tower reported, "Runway Condition 1/1/1 on ice, braking action good." On the next pass of the truck, our mu hit 40 and the RCC was raised to 5/5/5.



Airport operator's RCAM Mu (μ) Adjustment Column

Grooved Runways and Stopping

You may have heard that you can assume a wet runway that is grooved is "effectively dry." In fact, the EU says just that. You may have also heard that you cannot (as applied by many aircraft manufacturers) . As usual, there are caveats to both positions. If you are taking credit, you should know that a wet runway is not always "effectively dry." If you are not taking credit, you should realize that there are times when it is. Confused?

The definitive study on grooved runways was done in 1968 by the NASA Langley Research Center using a Convair 990 and a McDonnell Douglas F-4 Phantom II. The study revealed that the "effectively dry" question is not definitive. Landing distances on a wet, grooved runway are remarkably reduced almost to the point of being dry, until the water depth is greater than 0.1 in. or if there is any slush. At that point the distances are improved but not nearly as much. Balanced field lengths are "essentially dry" for grooved runways in a "wet and puddled" condition. If the runway is slush covered, the advantages of runway grooves are only "slight."

Regardless of how your aircraft manuals stand on the subject of grooved runways, the results of the study should impact how you interpret the charts in those manuals.

Once you've made the decision that the runway condition is good enough to land, you need to remind yourself of what exactly has to happen to get stopped within the confines of that runway. If you don't routinely land the airplane "by the book," you should remind yourself of the procedures your manufacturer used when achieving aircraft certification. These deviations add up.

Most aircraft are expected to land off a 3-deg. glidepath, crossing the threshold at 50 ft., and touching down about 1,000 ft. down the runway. Changes to the glidepath, threshold crossing height and touchdown point all have an impact on landing distance. While there is precision in the first two factors, nailing the touchdown point can be a problem.

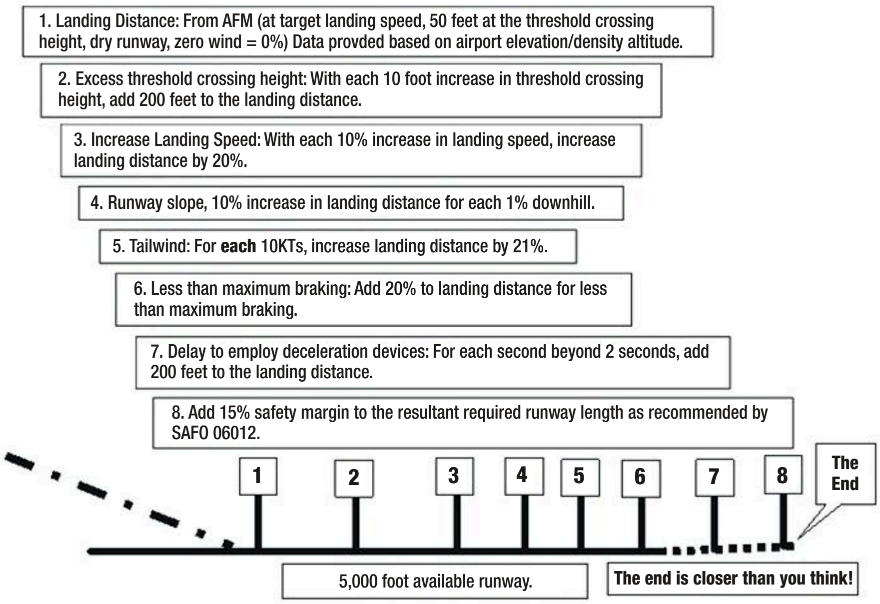
We know intuitively that the landing flare consumes distance, but something inside us also says that must have been accounted for in the aircraft certification. Well, it was. But it may not be the same idea of a flare as you might think. Remember the pilots certifying the airplane are trying to show how it can use short runways so they can sell more of them. Your objective is different. All of this is of critical importance when trying to predict your airplane's braking performance.

SAFO 06012 matter-of-factly points out that landing distances determined in compliance with 14 CFR Part 25 and published in the FAA-approved AFM "do not reflect operational landing distances." In fact, "flight test and data analysis techniques for determining landing distances can result in the use of high touchdown sink rates [as high as 8 ft. per second] and approach angles of -3.5 deg. to minimize the airborne portion of the landing distance."

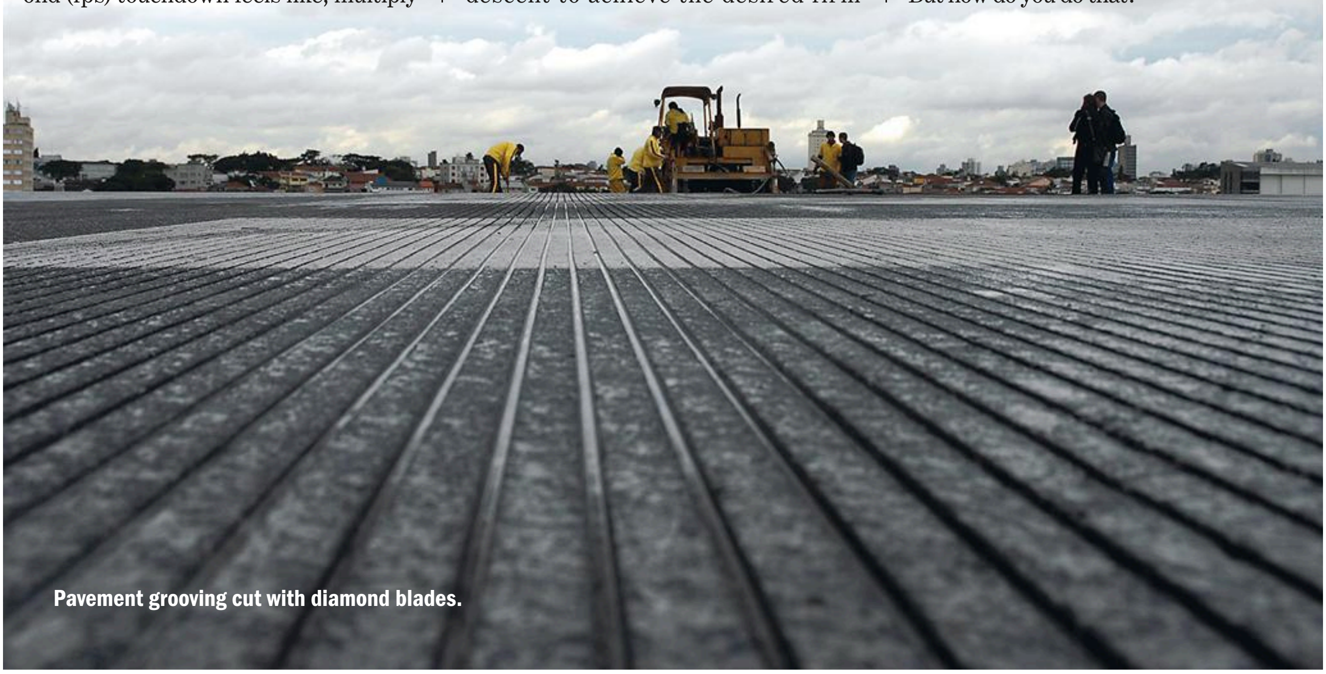
To get an idea of what an 8 ft. per second (fps) touchdown feels like, multiply that by 60 to get 480 ft. per minute (fpm) and consider a normal instrument approach requires a descent rate of 600 to 700 fpm. So, you are not even cutting your glidepath in half. Very few manufacturers publish their touchdown rates, but there are exceptions. The Gulfstream G550, for example, uses the example touchdown rate of 480 fpm.

AC 91-79A reminds us that "a proper flare reduces the aircraft's rate of descent to achieve the desired firm landing." However, it notes, "a firm landing does not mean a hard landing, but rather a deliberate or positive touchdown at the desired touchdown point. A landing executed solely for passenger comfort considerations, which extends the touchdown point beyond the touchdown zone (TDZ), is not impressive, desirable or consistent with safety or regulations. It is essential to fly the airplane onto the runway at the target touchdown point." But how do you do that?

The Effects of Compound Factors—The End Is Closer Than You Think

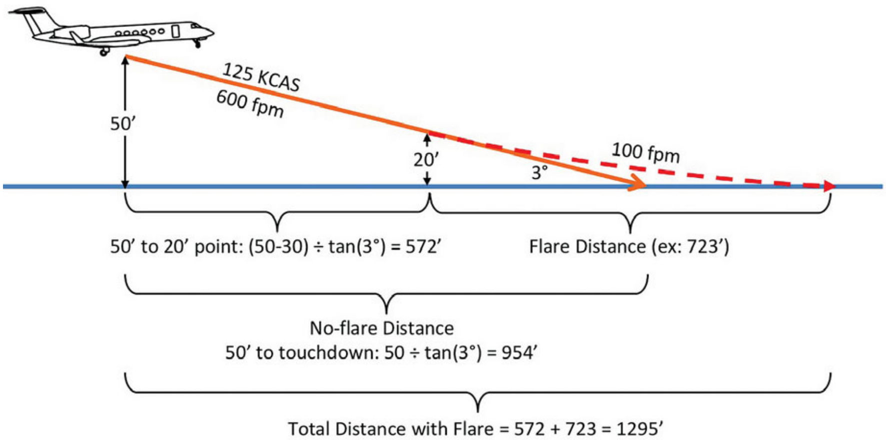


Landing distance compound factors, AC91-97A, Table 1



Pavement grooving cut with diamond blades.

NASA



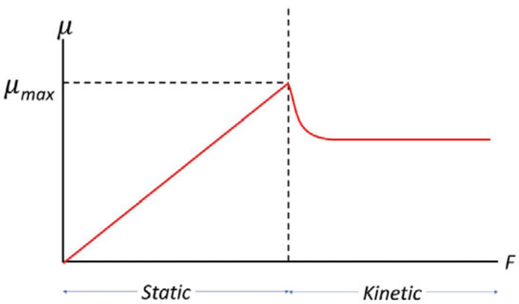
Example landing flare math, from Aim Point vs. Touchdown

My technique in every Gulfstream that I have flown is to attempt to cut my descent rate to about 100 fpm, as opposed to the conventional "flare to 0 in." method. At 100 fpm the landing gear struts have just enough give to provide a reasonably soft touchdown without the risk of misjudging "0 in." and ending up with a float. Going through the math, cutting a 600-fpm glidepath to 100 fpm at 20 ft. only adds 300 ft. to the landing distance. I can live with that. But when the runway is coated with a layer of water or other contamination, a firmer touchdown is called for.

We all know that hydroplaning occurs when the tire no longer has enough contact with the surface so as to maintain a one-to-one movement of rubber against that surface. In other words, the tire slips. And once it starts slipping, you have less stopping power until you stop the slipping.

If you really want to understand that, a physics lesson is in order. Recall that you can think of the coefficient of friction, μ (mu), as the amount of grip you get out of your tires against the pavement. You can diagram a changing μ against the force applied to the objects where the friction is being measured. The higher the μ the better the friction and your stopping power. You can think of the "F" in the chart above as the amount of friction you are asking from your brakes. The harder you press, the higher the "F" you expect. Notice that the μ, or your stopping force, goes up and up to a point. This is called "static friction," and once the tire breaks free from the surface, you have slippage and the stopping force goes down. This is called "kinetic friction." The only way to get the stopping force back is to ease off on the brakes and wait for the deceleration to catch up. That isn't ideal, of course.

So, the key to success when it comes to stopping on a wet or contaminated runway is to get your braking up to but short of that point where static friction turns to kinetic friction. That's something your anti-skid brake system can do better than you can, but you can help with a firm touchdown to break through that layer of contamination. Gently "kissing" the runway with the tire increases the chances it will not be rotating when it finally makes rubber-to-runway contact and therefore increase the likelihood of hydroplaning.



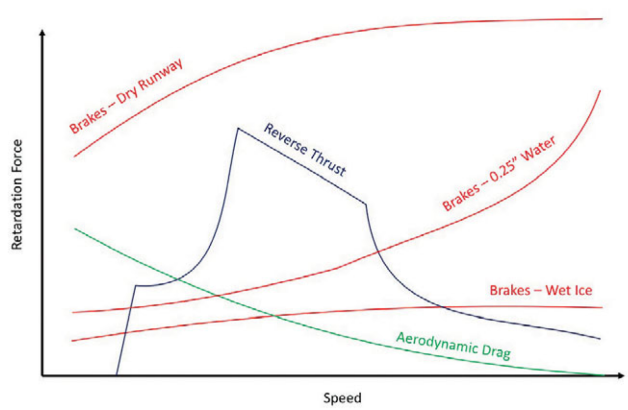
Static versus kinetic friction

After Touchdown

There are three primary forces available for deceleration during the landing rollout process: wheel braking, aerodynamic drag and reverse thrust/propeller, if available. Minimum landing distance is obtained by an extensive use of the wheel brakes for maximum deceleration. If minimum landing distance isn't needed, such as during a "normal" landing where there is considerable excess runway available, the aerodynamic drag of the aircraft can slow the airplane to minimize wear and tear on the tires and brakes. But this only works during the early stages of the landing rollout. Studies show that the use of aerodynamic drag is applicable only for deceleration to 60 to 70% of the touchdown speed. Below this, aerodynamic drag is so slight as to be of little use.

Those same studies show that timely deployment of spoilers will increase drag by 50% to 60%, but more importantly, deployment of the spoilers increases wheel loading by as much as 200%. This increases the tire-to-ground friction force, making the maximum tire braking forces available.

When minimum landing distances are needed, braking friction is the main source of deceleration when the runway is dry. When the runway is wet or slippery, reverse thrust (if the airplane is so equipped) may be the dominant deceleration force just after touchdown, and throughout the deceleration if the runway has poor or worse braking conditions. As the airplane slows down, the wheel brakes become the dominant deceleration force. For aircraft with anti-skid systems, maximum wheel braking should be applied immediately after all wheels are down. (Applying the brakes



Retardation forces on landing, a generic aircraft.

Runway Condition	Reported Braking Action	Factor to Apply to (Factored) Dry Runway Landing Distance
Wet Runway, Dry Snow	Good	0.9
Packed or Compacted Snow	Fair/Medium	1.2
Wet Snow, Slush, Standing Water, Ice	Poor	1.6
Wet Ice	Nil	Landing is Prohibited

Dry Runway Multiplication Factors, from SAFO 06012, Table 2

with the nosewheel in the air could cause it to slam down harder than desirable or for differences between contamination on individual tires to cause directional control problems.) For airplanes without an antiskid system, slow back pressure should be applied to the yoke such that it will not raise the nose of a nose gear airplane for aerodynamic braking while maximum braking that will not cause skidding is applied.

If the airplane is equipped with autobrakes, manufacturers recommend their application for all landings on contaminated runways. Autobrakes are applied earlier in the landing roll, and to the level selected for the anticipated landing condition, and runway available.

If braking is sustained and aggressive, such as during an aborted takeoff, pilots should be aware of the tendency to relax brake pressure as the airplane slows. It may be that our inner ears sense we are stopped before we actually are, it may be a matter of misjudging the speed, or it may simply be the effect of adrenaline. No matter the cause, pilots should maintain maximum braking until bringing their aircraft to a complete stop whenever the stopping distance margin is small.

Performance Data

There are four possibilities when it comes to published performance data regarding landing on a runway that is less than dry: (1) The data doesn't exist; (2) the data for a wet runway is nothing more than a 15% additive; (3) the data is unapproved and issued as advisory only; or (4) the data is a result of actual tests. You should know the source of the data in your manual. Only then can you approach everything about this topic with a sound foundation.

Manufacturer-supplied landing performance data for conditions worse than a dry, smooth runway is normally based on the dry runway landing performance, adjusted for a reduced airplane braking coefficient of friction.

If wet or contaminated runway landing distance data are unavailable, the factors in Table 2 of SAFO 06012 should be applied to the preflight planning (factored) dry runway landing distances determined in accordance with the applicable operating rule (*e.g.,* Parts 91.1037, 121.195(b) or 135.385(b). These factors include the 15% safety margin recommended by this SAFO and are considered to include an air distance representative of normal operational practices.

You should learn to fly your airplane onto the runway and determine how much runway your normal techniques require. Then you should compare these to your AFM numbers to see how much more runway you routinely require.

Putting It All Together

Have you ever landed 23 kt. fast? Yeah, me too. How about with a tailwind? Yup, same here. How about on a runway that is just barely long enough? I've done that a few times. Now, what about all three of those combined into one landing? I've never done that. I am betting the Citation pilots in N262Y on Oct. 1, 2010, bet they never did either. Just prior to the landing at Dare County Regional Airport in Manteo, North Carolina, the PIC asked the SIC what he thought, to which the right seater responded, "It's up to you." That turned out to be the wrong answer.

The pilots touched down at an excessive airspeed (23 kt. above VREF), more than 1,200 ft. down a wet, 4,305-ft.-long runway, leaving about 3,100 ft. for the airplane to stop. According to manufacturer calculations, about 2,710 ft. of ground roll would be required after the airplane touched down, assuming a touchdown speed at VREF; a longer ground roll would be required at higher touchdown speeds.

Although the crew applied speed brakes, thrust reversers and brakes immediately after the nosegear touched down, the airplane departed the end of the runway at about 40 kt. and came to rest some 50 ft. into the Croatan Sound. Both pilots and the five passengers suffered minor injuries in the accident; damage to the Citation was listed as "substantial."

Landing on anything less than a dry runway ought to set into motion an additional set of precautions in your normally cautious pre-landing decision making. You need to get relevant and recent weather and go through your airplane's performance numbers to make sure it will all work out, on paper at least. On a wet runway, you need to add 15% to the dry runway numbers if your manufacturer doesn't provide wet runway data. If the runway is grooved, you might be able to consider it "effectively dry" if your manufacturer permits this. But once the contamination gets much deeper than 0.1 in. or slush is involved, that runway may not be effectively dry after all.

Commercial operators have a number of safety factors to consider prior to departure under such circumstances and must add 15% to landing distance numbers once en route; Part 91 operators should do this, too. You should also remember that the way you flare the airplane, apply reverse thrust and braking have a big impact on your stopping distance. Many pilots get most of this wrong.

In reviewing reports of overrun accidents from contaminated runways, most pilots say, "I would never do that." While some of the crews who failed to stop within the confines of the runway were careless or should not have been in their cockpits to begin with, some were quite professional and thought they were doing everything just right. The crux of the matter is that we just don't have a precise way to measure the runway's condition at our moment of touchdown and little certainty about how our aircraft's braking system will respond. Until we do, it behooves us to do everything by the book and, even then, look at everything to do with stopping on a wet or contaminated runway with a very skeptical eye. BCA

NTSB

The conclusion of the flight of Citation N262Y into Dare County Regional Airport, Manteo, North Carolina (KMQI).