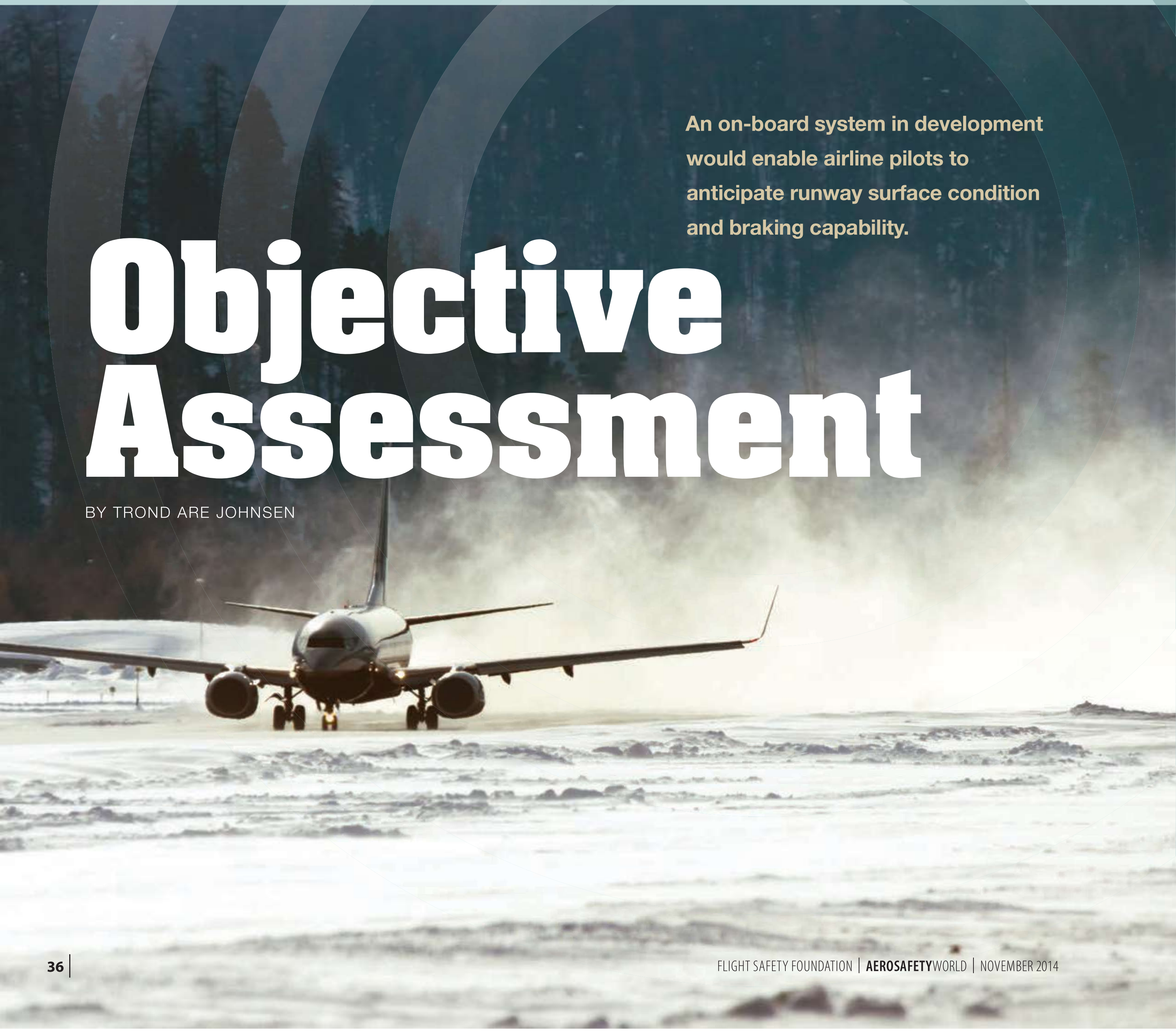
Advances in technology and aviation industry safety initiatives have significantly reduced commercial air transport accidents, but runway safety–related events generally, and runway excursions specifically, persist. Accurately assessing runway surface condition and braking capability have not received the same technological focus as contributing factors in other types of accidents. This article presents progress to date on an on-board system in development that would intercept flight data parameters for real-time analysis early in the landing roll, reference stored data representing the specific airplane's known landing performance and apply an algorithm that helps the flight crew to objectively recognize the actual runway condition and to accurately assess their airplane's braking capability.

Potential delivery modes for this information include near–real time "data push" integration into flight operations/dispatcher flight following tools, existing landing analysis systems and directly informing the flight crew.

An on-board system in development would enable airline pilots to anticipate runway surface condition and braking capability.

Objective Assessment

BY TROND ARE JOHNSEN



Southwest Airlines Flight 1248, which overran the runway while landing at Chicago Midway International Airport on a snowy night in December 2005, has come to exemplify the shortcomings in the reporting of braking capability on contaminated runways. This accident, which resulted in the death of a young passenger in an automobile that was struck by the Boeing 737-700 after the aircraft crashed through a blast fence and an airport perimeter fence, has served as a catalyst for several industry initiatives and renewed thinking.

Flight Safety Foundation has addressed runway safety repeatedly, and recommended in 2009's *Reducing the Risk of Runway Excursions: Report of the Runway Safety Initiative*[1] that "a universal, easy-to-use method of runway condition reporting should be developed to reduce the risk of runway excursions."

The U.S. National Transportation Safety Board (NTSB), in its Flight 1248 accident report, recommended that the U.S. Federal Aviation Administration (FAA) "demonstrate the technical and operational feasibility of outfitting transport category airplanes with equipment and procedures required to routinely calculate, record and convey the airplane braking ability required and/or available to slow or stop the airplane during the landing roll."[2]

In cooperation with United Airlines, Kongsberg Aeronautical has tested the prototype on-board system, similar to the one proposed in this NTSB accident report, and which also responds to the conclusions and recommendations of the FSF initiative. Installed on United's fleet of Boeing 737s, the system has been subjected to a validation program in cooperation with the FAA William J. Hughes Technical Center. The validation has shown that the Kongsberg Aeronautical system performs as expected and intended.

Outfitting transport category airplanes to use flight data to calculate braking ability may seem a straightforward undertaking, but it is not. There are technical as well as practical issues involving ease of use to consider, including:

- Comprehensiveness of assessment system or model;
- Applicability to guidance materials' advisory data for stopping distance; and,
- Data gathering, flight data integrity and confidentiality.

As to comprehensiveness, the landing roll is a dynamic process with a multitude of factors, including ambient conditions, contributing to the airplane's braking capability at different phases. To single out the braking factors associated with the tire-surface interface is an intricate task.

One scientific approach to this challenge might be to mathematically model and emulate the landing roll and all of its constituent factors for defined ambient conditions. It would hardly be a viable and practical solution, however, because it would be challenging to create a model capable of covering all of the variables and assessing interrelatedness of the factors. Furthermore, being able to obtain the required quality of input parameters would be difficult, even if all the needed input parameters could be acquired.

The objective of any assessment system or model should be to capture the essence of the landing roll, in terms of stopping capability, for use in conjunction with the stopping distance guidance information from the aircraft manufacturers.

As to applicability, airlines base their operational assessment of stopping distances primarily on airplane manufacturers' guidance, which is contained in the quick reference handbook, flight crew operations manual and the flight planning and performance manual. Boeing, for example, has classified its airplane braking coefficient and associated braking action categories as *dry*, *good*, *medium* and *poor*, and provided the corresponding landing distances.[3] This complies with the FAA's Takeoff and Landing Performance Assessment Aviation Rulemaking Committee (TALPA ARC) recommendation for an industry initiative except that the TALPA ARC called for two more intermediary categories — *good to* *medium* and *medium to poor.* Although guidance information details stopping distances down to exact feet, it is important to understand that the data are not absolute; they are based to an extent on empirical data as well as extrapolations.

Thus, providing data for input to a model at a level of accuracy beyond what is required for the aircraft manufacturers' guidance material would be meaningless.

As to data gathering, agreements between airlines and their pilot unions strictly govern the use of flight data; integrity, confidentiality and the framework for managing flight data are important. When flight data change hands and are transferred to a third party in full or in part, the data may become susceptible to compromise and breach of confidentiality, either intentionally or unintentionally. Any effort to reduce the amount of flight data subject to transfer is desirable in terms of both integrity and confidentiality.

Start of a Partnership

A braking action test program was launched at Continental Airlines (since merged with United Airlines) in 2010 by the carrier's flight operational quality assurance group. The program's testing was conducted in cooperation with Kongsberg Aeronautical, which provided the algorithm that was adapted and uploaded into the Boeing 737 test aircraft. The program, which was designed to obtain braking action information through on-board calculations, was quickly streamlined and dynamic noise was eliminated from the source data.

Early results of the braking action test contributed to identifying operational safety action items, which were featured in *AeroSafety World* in 2013.[4] Subsequently uploaded on all of United's 737NGs, the Kongsberg Aeronautical system now acquires data daily on every flight in this fleet. It is a "read only" system located within the aircraft condition monitoring system (ACMS) software and uses flight data from previous landings to calculate maximum braking capability. At the end of each landing roll, only the calculated braking

Pilot Version of Matrix

Braking Action Report PIREPs			
Term	**Definition**	**Associated Runway Surface Condition**	**Runway Condition Code**
Dry		**Any temperature and:** • Dry	6
Good	Braking deceleration is normal for the wheel braking effort applied. Directional control is normal.	**Any temperature and:** • Wet surface (smooth, grooved or PFC runway) • Frost **Any temperature and ⅛ in (3.2 mm) or less of:** • Water • Slush • Dry snow • Wet snow	5
Good to Medium	Brake deceleration and controllability is between *good* and *medium*.	**At or below -13°C (9°F) and:** • Compacted snow	4
Medium	Braking deceleration is noticeably reduced for the wheel braking effort applied. Directional control may be slightly reduced.	**Any temperature when:** • Wet (when runway is reported as "slippery when wet") **At or below -3°C (27°F) and greater than ⅛ in of:** • Dry or wet snow **Above -13°C and at or below -3°C and:** • Compacted snow (any depth, depth not reported)	3
Medium to Poor	Brake deceleration and controllability is between *medium* and *poor*. Potential for hydroplaning exists.	**Any temperature and greater than ⅛ in of:** • Water • Slush **Temperature above -3°C and:** • ⅛ in and greater of dry or wet snow • Compacted snow (any depth, depth not reported)	2
Poor	Braking deceleration is significantly reduced for the wheel braking effort applied. Directional control may be significantly reduced.	**At or below -3°C and:** • Ice	1
Nil	Braking deceleration is minimal to nonexistent for the wheel braking effort applied. Directional control may be uncertain.	**Any temperature and:** • Wet ice • Water on top of compacted snow • Dry or wet snow over ice **Temperature above -3°C and:** • Ice	0

PFC = porous friction course; PIREPs = pilot reports

Source: Trond Are Johnsen

Table 1

action information, in deidentified form, was transmitted to a ground station for the research. The transmitted information therefore could not reflect on the skill and airmanship of the pilots.

Employing a streamlined version of the Boeing aircraft braking coefficient calculation, the on-board prototype system detects *friction-limited braking situations* — situations in which increased brake pressure does not yield increased deceleration, which is the point of maximum braking capability. Braking capability/braking action assessment also is aligned with the guidance material/advisory data for landing distance from the manufacturer.

Cooperation With FAA

Based on the promising results demonstrated through the early 737 tests, the FAA's technical center established a cooperative research and development agreement (CRDA) with Kongsberg Aeronautical in 2012 to jointly evaluate uses for braking action information in real-time, runway-slipperiness condition reporting. The research will assist the FAA Terminal Area Safety Research Program in investigating whether flight data on landing airplanes can provide an accurate and timely assessment of runway slipperiness to prevent runway accidents.

The current system does not capture all of the previously noted dynamic aspects of an airplane's landing roll. It does, however, capture the essence of the landing roll, thereby providing relevant and clear information — quality input parameters to the system that enhance the landing distance advisory data provided by airplane manufacturers. The essence of the CRDA was to analyze and discuss a few of the system's features that differentiate it from conventionally conducting a scientific, full emulation of the landing roll. Among these features are the following:

- Use of a portion of the runway;
- Simplified ambient conditions;
- The impact of runway slope; and,
- Transferability to other aircraft.

For a better understanding of these aspects within the validation process, a brief discussion follows.

Portion of Runway

Do flight crews need to consider the full length of the runway or just a portion to be able to assess braking capability? As noted, separating deceleration force associated with the tire-surface interface from other braking factors is complex. Incorporating this factor in the early phase of an actual landing roll at first sounds more academically interesting than practically valuable. There are several arguments that support such an approach, however.

Any landing, regardless of runway surface condition or the application of braking force at the early phase of the landing roll, can "feel good" to pilots because aerodynamic drag and reverse thrust produce deceleration forces subjectively perceived to result from the brake application. The diminishing impact of the drag will be felt when speed slows below 100 kt. Although present throughout the landing roll, the deceleration benefit from aerodynamic drag therefore can be disregarded for practical purposes at lower ground speeds.

Reverse thrust works much like a parachute and is more effective at higher speed. A common practice is to stow the thrust reversers when the aircraft speed decreases to between 80 and 60 kt. Therefore, the deceleration benefit from reverse thrust also can be disregarded for practical purposes at lower ground speeds.

Winter conditions can create situations in which the friction heating of tires throughout the landing roll affects the tire-surface interface by reducing braking action toward the end of the landing roll. This is particularly valid with snow or icy conditions. In fact, in a number of runway overrun accident reports, pilots describe how they considered braking action good initially and believed that it deteriorated. The United 737 braking action test program did not involve runway overruns, but similarly received reports from participating pilots who described feeling "apprehension" when conditions became slippery as the landing roll progressed.

These tests showed that using just a portion of the runway to make instantaneous assessments could provide the flight crew ample information, essentially revealing critical aspects of braking ability in real time.

Simplified Ambient Conditions

There is a trade-off for flight crews between knowing ambient weather conditions in great detail and having the ability and time to properly assess them. Reports of meteorological conditions, such as temperature, air pressure, wind speed and wind direction, only provide approximate information and may not always be current. Wind and wind direction, air pressure, etc. have a declining impact on stopping capability as the aircraft slows during the landing roll. Accounting for the weather-condition impact at the initial phase of the landing roll would be complicated and, likely, in vain. The reason is that the end portion of the landing roll provides the information critical to understanding braking ability. Therefore, a simplified approach to gathering data on ambient weather conditions has proved sufficient in the Kongsberg Aeronautical system.

Runway slope also normally is taken into consideration among ambient conditions for takeoff and landing safety analysis by means of advisory data. However, runway slope is not a consideration in this system because the slope has, for practical purposes, an inconsequential effect. Runway slope rarely exceeds 2 percent, and most U.S. airports have slopes of less than 1 percent.

Aircraft Transferability

Braking coefficient values are the same for all types/sizes of aircraft. This principle was considered in TALPA ARC recommendations. Aircraft of different sizes may nevertheless experience differences in braking action, given the same objective runway surface conditions. This analysis did not include regional jets, but the analysis shows that there are commonalities and transferability between aircraft within categories, such as the 737 series and the Airbus A320 series. When comparing estimated landing distance, given similar braking action conditions and using aircraft manufacturer guidance material, there are clear parallels for these two aircraft series.

Pilot reports and feedback formed part of the initial phase of the braking action test program. Pilots evaluated situations in which the Kongsberg Aeronautical system detected braking action conditions that were less than good.[5] Landing data and their feedback revealed consistency with actual and prevailing weather conditions, indicating that the system was performing as expected and intended.

As part of today's Phase 2 validation process, FAA engaged the University of Massachusetts and a research group to perform an extensive analysis to assess the correlation between prevailing weather conditions and braking capability as derived from the system.

Because slippery runways are not just a winter problem, the analysis included airports in tropical locations. A foundation for the analysis was one year of information acquired from United's 737 fleet, with the associated and system-calculated airplane-based braking action figures. Historic weather information was consulted to obtain prevailing conditions for each airport that corresponded to the date and time of every landing that involved friction-limited braking conditions.

In summary, unless aircraft manufacturers can derive certified, perfect landing/stopping distances for any given variation of runway conditions, the aviation industry's primary goal must be to develop a system in compliance with guidance material and advisory data. Today, such advisory data is sorted into six "braking action" categories, according to the TALPA ARC matrix (Table 1, p. 38). Any attempt to furnish braking capability information with higher accuracy — beyond the level of advisory data — will not serve any practical purpose. Capturing the essence of the braking coefficient from the aircraft itself during each actual landing roll, however, could provide near-real time information to the flight crew.

Beyond Validation

In aviation, a system has no value unless it can provide the right data to the right users at the right time. This requires schemes for distribution and integration with appropriate user tools and interfaces. At United Airlines, upcoming and post-validation activities involve an early-phase integration with dispatcher tools.

The real potential in the Kongsberg Aeronautical system lies in pooling information from, ideally, all aircraft in service, although obtaining data from several large airlines may prove sufficient. With a common information pool, all airlines could benefit. The power of the system is in the aggregation of the collected information.

Even though airlines fiercely compete for the business of the traveling public, the aviation industry has a longstanding history of cooperation when it comes to safety. With such technology becoming available, it is time to more accurately and efficiently assess runway surface condition and braking capability through joint effort and cooperation among airlines.

Trond Are Johnsen is the general manager of Kongsberg Aeronautical, and has managed the test program since its beginning. His background includes development of technology from early phase to user applications.

Notes

1. Flight Safety Foundation. *Reducing the Risk of Runway Excursions: Report of the Runway Safety Initiative*. May 2009. Available at <flightsafety.org>.

2. NTSB. Accident Report NTSB/AAR-07/06, *Runway Overrun and Collision; Southwest Airlines Flight 1248, Boeing 737-7H4, N471WN; Chicago Midway International Airport, Chicago, Illinois; December 8, 2005*. Adopted Oct. 2, 2007.

3. These landing distances take into account air distance and safety margins for conditions other than *dry*.

4. Vizzoni, Joe. "Your Slip Is Showing." *AeroSafety World* Volume 8 (May 2013): 12–16.

5. Ibid.