National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

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In reply refer to: A-07-58 through -64

The Honorable Robert A. Sturgell
Acting Administrator
Federal Aviation Administration
Washington, D.C. 20591

On December 8, 2005, about 1914 central standard time, Southwest Airlines (SWA) flight 1248, a Boeing 737-7H4, N471WN, ran off the departure end of runway 31C after landing at Chicago Midway International Airport (MDW), Chicago, Illinois.[1] The airplane rolled through a blast fence, an airport perimeter fence, and onto an adjacent roadway, where it struck an automobile before coming to a stop. A child in the automobile was killed, one automobile occupant received serious injuries, and three other automobile occupants received minor injuries. Eighteen of the 103 airplane occupants (98 passengers, 3 flight attendants, and 2 pilots) received minor injuries, and the airplane was substantially damaged. The airplane was being operated under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 and had departed from Baltimore/Washington International Thurgood Marshall Airport, Baltimore, Maryland, about 1758 eastern standard time. Instrument meteorological conditions prevailed at the time of the accident flight, which operated on an instrument flight rules flight plan.

The National Transportation Safety Board determined that the probable cause of this accident was the pilots' failure to use available reverse thrust in a timely manner to safely slow or stop the airplane after landing, which resulted in a runway overrun. This failure occurred because the pilots' first experience and lack of familiarity with the airplane's autobrake system distracted them from thrust reverser usage during the challenging landing.

Contributing to the accident were SWA's 1) failure to provide its pilots with clear and consistent guidance and training regarding company policies and procedures related to arrival landing distance calculations; 2) programming and design of its on board performance computer (OPC), which did not present inherent assumptions in the program critical to pilot decision-making; 3) plan to implement new autobrake procedures without a familiarization period; and 4) failure to include a margin of safety in the arrival assessment to account for

[1] For more information, see *Runway Overrun and Collision, Southwest Airlines Flight 1248, Boeing 737-7H4, N471WN, Midway Airport, Chicago, Illinois, December 8, 2005*, Aviation Accident Report NTSB/AAR-07/06 (Washington, DC: NTSB, 2007).

operational uncertainties. Also contributing to the accident was the pilots' failure to divert to another airport given reports that included poor braking action and a tailwind component greater than 5 knots. Contributing to the severity of the accident was the absence of an engineering materials arresting system, which was needed because of the limited runway safety area beyond the departure end of runway 31C.

On Board Performance Computer Displays and Underlying Assumptions

The Safety Board evaluated the clarity of the information displayed to the pilots on the SWA OPC and the underlying assumptions (including reverse thrust credit) upon which the resultant landing distance assessments were based. Pilots use a variety of aids to accomplish airplane performance calculations, including tabular performance charts. SWA provides its pilots with an OPC for such calculations. Using an OPC or similar electronic computing device instead of tabular charts can decrease the pilots' workload because the computing device can automatically apply adjustments and interpolate based on the operator's programming. However, if pilots misunderstand the output because they are unaware of critical performance calculation assumptions, use of an electronic computing device can lead to errors in decision-making.

For example, as the accident pilots neared MDW, they used the OPC to calculate the airplane's landing distance multiple times, assessing updated weather conditions and stopping margins on runway 31C under both fair and poor braking action conditions. All of the resultant OPC calculations indicated that they could land and stop the airplane in the available runway length. The OPC indicated a stopping margin of about 560 feet before the end of the runway for fair braking action and about 40 feet before the end of the runway for poor braking action. However, evidence indicates that the landing distances displayed on the OPC could have been misleading to the crew because the pilots were not aware of at least two underlying OPC assumptions, neither of which was displayed on the OPC. Both of these assumptions resulted in OPC indications showing larger (more favorable) stopping margins.

One OPC assumption that the accident pilots were not aware of was that stopping margins displayed by the OPC for poor runway conditions were in some cases based on a lower tailwind component than that which was entered. Typically, the stopping margin output corresponded to the presented tailwind component. However, the tailwind component exceeded the 5-knot limit for poor runway conditions, but the displayed stopping margin was instead based on the tailwind limit of 5 knots, not the actual 8-knot tailwind component, as entered by the flight crew. Although in these cases the actual tailwind component is highlighted with white text on a red background, and the tailwind component limits are presented at the bottom of the display in white text on a black background, there is no indication that the stopping margin is not based on the presented tailwind component.

For the accident landing, the OPC-calculated stopping margin of 40 feet for poor runway braking action was based on the company-programmed 5-knot tailwind component limit, despite the fact that the display showed the actual 8-knot tailwind component based on the winds input by the pilots. Calculations based on the 5-knot tailwind limit resulted in more favorable displayed stopping margins. If the OPC calculations had been based on the actual 8-knot tailwind component, the stopping margin would have indicated that there was not enough runway available to land with poor braking action. This information would have provided the pilots with a more conservative and realistic indication of the expected landing performance. To highlight negative stopping margin values and to alert pilots that it is not safe to land on a particular runway, SWA's OPC uses alternate graphics and the color red on the display.[2] Cockpit voice recorder (CVR) and postaccident interview evidence indicated that both pilots were uncomfortable with the low positive stopping margins exhibited by the OPC. Had a negative stopping margin been shown and highlighted on the OPC display, the pilots would have been further alerted to the potential hazards involved in a landing on runway 31C at MDW under the accident conditions.

The accident pilots were also not aware that the 737 stopping margins computed by the SWA OPC were designed to incorporate the use of reverse thrust for the 737-700 model only (not the -300 or -500), which resulted in more favorable stopping margins. Postaccident interviews with SWA pilots indicated that some (including the accident crew) assumed that none of the 737 OPC landing distance calculations took into account the use of reverse thrust. Because of this, the accident pilots believed that their intended use of reverse thrust during the landing roll would provide them with several hundred feet more stopping margin than the OPC estimated. (Interviews with other SWA pilots indicated that they were not uniformly aware of this and other landing distance assumptions, such as air distance.) The Safety Board concludes that if the pilots had been presented with stopping margins associated with the input winds or had known that the stopping margins calculated by the OPC for the 737-700 already assumed credit for the use of thrust reversers, the pilots may have elected to divert.

Federal Aviation Admnistration (FAA) advisory material regarding electronic flight performance calculations[3] suggests that the output be displayed in a manner that is understood easily and accurately and that users of such devices should be aware of any assumptions upon which the flight performance calculations are based. There is no specific guidance suggesting that these assumptions be as clear to pilots as similar information would be on a tabular chart, however. Such clarity is critical because airplane performance data and related OPC assumptions are not consistent across manufacturers, airplane models, or operators and may be based on information other than what the pilots entered. In the case of the accident flight, the SWA OPC screen did not display OPC assumptions (for example, the thrust reverser credit assumptions) when they were applicable; this information would have been readily available on a tabular chart. Therefore, the Safety Board concludes that presentation of the OPC assumptions upon which landing distance calculations are based is critical to a pilot's decision to land. Therefore, the Safety Board believes that the FAA should require all 14 CFR Part 121 and 135 operators to ensure that all on board electronic computing devices they use automatically and clearly display critical performance calculation assumptions.

As a result of its evaluation of the accident pilots' decision to land and their actions during the approach and landing, the Safety Board determined that if the pilots had been aware of existing company guidance and policies in several areas, including runway braking action

[2] Negative values are presented in brackets as white digits inside of a red block instead of the standard black digits against a white background.

[3] There are currently no requirements for the design and certification of airplane OPCs; all current guidance is advisory in nature.

reports and the underlying assumptions factored into OPC stopping margin calculations, they would have made a better-informed landing decision. Accident evidence indicated that other SWA pilots were similarly unaware of SWA's guidance and policies in these areas. Therefore, the Safety Board concludes that SWA did not provide its pilots with clear and consistent guidance and training regarding company policies and procedures in several areas, including interpretation of braking action reports and the assumptions affecting landing distance assessments. Therefore, the Safety Board believes that the FAA should require all 14 CFR Part 121 and 135 operators to provide clear guidance and training to pilots and dispatchers regarding company policy on surface condition and braking action reports and the assumptions affecting landing distance/stopping margin calculations, to include use of airplane ground deceleration devices, wind conditions and limits, air distance, and safety margins.

Thrust Reverser Usage and Autobrakes

According to SWA procedures, the flying pilot was required to deploy the thrust reversers as soon as possible after nosewheel touchdown for all landings. SWA guidance especially emphasized immediate deployment of reverse thrust when braking actions were reported to be less than good. The accident pilots reported that they were aware of the company's reverse thrust policies and routinely carried them out; however, for the accident landing, the captain (the flying pilot) did not deploy reverse thrust immediately after the airplane touched down. During postaccident interviews, the captain stated that he tried to deploy the thrust reversers promptly after touchdown but was not successful. SWA procedures also required the monitoring pilot to be attentive for procedural deviations during all landings. The first officer stated that, when he realized that the captain had not deployed the thrust reversers, he moved the thrust levers to command reverse thrust (thrust reverser activation was initiated about 15 seconds after touchdown according to flight data recorder [FDR] data). FDR data indicated that the thrust reversers were eventually fully deployed about 18 seconds after touchdown, and the pilots held maximum reverse thrust until the airplane came to a stop off the end of the runway.

The Safety Board's review of FDR data from four other SWA 737s that landed and came to a stop on runway 31C at MDW during the 21 minutes before the accident indicated that reverse thrust on these airplanes was deployed promptly after landing. Postaccident calculations showed that, if the pilots had promptly initiated and maintained maximum reverse thrust throughout the landing roll, the airplane would not have run off the end of the runway. Therefore, the Safety Board concludes that the pilots would have been able to stop the airplane on the runway if they had commanded maximum reverse thrust promptly after touchdown and maintained maximum reverse thrust to a full stop.

Despite the captain's reported difficulties in his initial attempt to deploy the thrust reversers, they extended normally in a coordinated manner for the first officer. On the basis of postaccident examination and interviews, the Safety Board concludes that the pilots' delay in deploying the thrust reversers could not be attributed to mechanical or physical difficulties.

SWA planned to implement a new policy the week after the accident that would have required the use of autobrakes during landings under some conditions, including the accident landing conditions.[4] In preparation, SWA provided its pilots with a self-study training module on the system and related procedures. Information from the CVR indicated that the pilots discussed the new procedures and possible contingencies and ultimately agreed that use of the autobrakes would allow them to stop in the shortest distance and used the autobrakes on maximum setting during the accident landing. Their use of autobrakes when landing required a change in the sequence of landing tasks for both the flying pilot and the monitoring pilot. Before SWA's new autobrakes procedures took effect, procedures required the flying pilot to manually apply wheel brakes and deploy the thrust reversers simultaneously as soon as possible after touchdown. However, with the use of autobrakes, only one of these two tasks was required at touchdown; the prompt manual application of wheel brakes was no longer necessary. Research indicates that carrying out new procedures requires more effort and cognitive resources than does carrying out routine procedures and limits the number of tasks that can be carried out simultaneously.[5] Because of the pilots' concerns regarding the autobrakes and their unfamiliarity with the system's operation, it would have been natural for them to focus on the autobrake system's performance after the airplane touched down.

During postaccident interviews, both pilots reported that they were preoccupied by the autobrake system during the accident landing. The captain reported that his focus on the autobrake system performance distracted him from trying to deploy the thrust reversers again after his first attempt was unsuccessful. The first officer had the additional task of monitoring the autobrakes light on the front instrument panel during the landing rollout, although he reported that he maintained his focus outside of the cockpit and on their stopping performance. Research also indicates that activities that have been grouped together in an automatic task sequence require substantial effort to separate.[6] In this case, applying the wheel brakes would normally be accomplished with deployment of the thrust reversers, and omitting one of these linked activities (wheel brakes) could help explain omission of the other (thrust reversers). The pilots stated that, as the landing roll continued, they were not satisfied with the airplane's deceleration, and FDR data indicated that, about 12 seconds after touchdown, they transitioned from autobrakes to maximum manual wheel braking. FDR data indicated that the thrust reversers deployment was initiated 15 seconds after touchdown, with full thrust reverser deployment occurring 18 seconds after touchdown.

According to postaccident interviews with SWA personnel, similar distractions were observed in SWA pilots during the development of the company's autobrake program. SWA check airmen and their first officers reported concern prior to use and difficulty with the transition from using autobrakes to manual braking after touchdown; some were so distracted that they delayed reverse thrust application. Pilots also indicated that these challenges persisted

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[4] The accident pilots mistakenly believed that the company's autobrakes policy was already effective the day of the accident.

[5] See (a) S. Shiffrin and W. Schneider, "Controlled and Automatic Human Information Processing: II. Perceptual Learning, Automatic Attending and a General Theory," *Psychological Review*, vol. 84, no. 2, pages 127-190, 1977; (b) G. Logan, "Toward an Instance Theory of Automatization," *Psychological Review*, vol. 95, no. 4, pages 492-527, 1988; and (c) G. Logan and W.B. Cowan, "On the Ability to Inhibit Thought and Action: A Theory of an Act of Control," *Psychological Review*, vol. 91, no. 3, pages 295-327, 1984.

[6] See G. Logan, "On the Ability to Inhibit Complex Movements: A Stop-Signal Study of Typewriting," *Journal of Experimental Psychology: Human Perception and Performance*, vol. 8, no. 6, pages 778-792, 1982.

for the first few landings only, until they had the chance to acclimate to the new procedures. At the time of the accident, SWA's planned implementation of its autobrakes procedures did not include a familiarization period with the use of the autobrakes,[7] nor was one required by regulations. However, feedback from other SWA pilots should have alerted SWA management and the company's FAA principal operations inspector to the need for a familiarization or transition period.

The Safety Board concludes that the pilots' first use of the airplane's autobrake system during a challenging landing situation led to the pilots' distraction from the otherwise routine task of deploying the thrust reversers promptly after touchdown. Had SWA implemented an autobrake familiarization period in advance, such a period would have allowed pilots to become comfortable with the changed sequence of landing tasks. The Safety Board further concludes that the implementation of procedures requiring thrust reverser status confirmation immediately after touchdown may prevent pilots from inadvertent failure to deploy the thrust reversers after touchdown. Therefore, the Safety Board believes that the FAA should require all Part 121 and 135 operators of thrust reverser-equipped airplanes to incorporate a procedure requiring the non-flying (monitoring) pilot to check and confirm the thrust reverser status immediately after touchdown on all landings.

Preflight and Arrival Landing Distance Calculations/Assessments

Unlike preflight landing distance calculations, which Part 121 operators are required to perform before departure, operators are not required by the FAA to perform arrival landing distance assessments. Although many Part 121 operators (including SWA) do require their pilots to perform landing distance assessments before every landing, the FAA does not require or standardize arrival assessments as it does preflight assessments. As a result, operators are allowed to set their own policies and use data from various sources (for example, the manufacturer, in-house personnel, an outside contractor, etc.). Depending on the source, the data used may be less conservative than the manufacturer's data and may contain embedded assumptions related to landing and deceleration techniques, the airplane's braking ability for a given runway surface condition report, and/or the application of additional safety margins. If pilots are unaware of these embedded assumptions, they might believe that they need less landing distance than they actually do or have an inaccurate perception of how much braking effort will be needed on landing. Depending on an operator's policies, pilots may not be required to conduct arrival landing assessments; may conduct such assessments based on variable landing performance data sources, assumptions, and calculation methods; or may conduct such assessments based on data that include no additional safety margin. The Safety Board notes that SWA's arrival landing distance assessment practices exceeded those of many other operators; yet, the safety margin was inadequate to prevent this accident.

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[7] SWA had not initially planned to implement the new autobrake policy during the winter; however, delays associated with other procedures implemented simultaneously delayed the autobrake implementation date.

Safety Alert for Operators Discussion and Industry Practice Regarding Landing Distance Assessments

As a result of the SWA flight 1248 accident, the Safety Board issued urgent Safety Recommendation A-06-16, which asked the FAA to prohibit all 14 CFR Part 121 operators from using reverse thrust credit in landing performance calculations. The stated intent of this recommendation was to ensure adequate landing safety margins on contaminated runways. In response, in June 2006, the FAA issued an advance notice of its intent to issue mandatory Operations Specification (OpSpec) N 8400.C082, which would have required all Part 121, 135, and 91 subpart K turbojet operators to conduct landing performance assessments (not necessarily a specific calculation) before every arrival based, in part, on planned touchdown point, procedures and data at least as conservative as the manufacturer's, updated wind and runway conditions, and an additional 15 percent safety margin. However, the FAA subsequently decided not to issue the mandatory OpSpec at that time and, in August 2006, published Safety Alert For Operators (SAFO) 06012 as an interim guidance measure. SAFO 06012 addressed similar issues to the mandatory OpSpec, but operator compliance with the SAFO is, by definition, voluntary. Although the FAA published SAFO 06012 with the intent of pursuing rulemaking in the area of landing distance assessments, in the interim, operators are still not required to comply with its recommendations and, currently, many operators do not.

For example, on February 18, 2007, a Shuttle America Embraer ERJ-170 ran off the end of snow-contaminated runway 28 at Cleveland Hopkins International Airport, Cleveland, Ohio. The investigation to date has revealed that Shuttle America did not require its pilots to perform (and therefore did not incorporate landing distance safety margins into) arrival landing distance assessments. About 2 months later, a Pinnacle Airlines Bombardier Regional Jet CL600-2B19 ran off the end of snow-covered runway 28 at Cherry Capital Airport in Traverse City, Michigan. By contrast, the investigation into this accident showed that Pinnacle's OpSpecs required its pilots to perform arrival landing distance assessments (including a minimum 15 percent safety margin) per SAFO 06012; however, the pilots did not perform the required assessment before the accident landing. If an arrival landing distance assessment had been performed, given the existing conditions, Pinnacle's OpSpecs would have dictated that a diversion was required.

The Safety Board is concerned that, because of operational and conditional variations, it is possible for an airplane to use more of the landing runway than preflight (dispatch) calculations predicted and for pilots to continue to run off the end of contaminated runways.[8] The FAA concluded in SAFO 06012 that operator compliance with preflight landing distance planning requirements alone "does not ensure that the airplane can safely land within the distance available on the runway in the conditions that exist at the time of arrival, particularly if the runway, runway surface condition, meteorological conditions, airplane configuration, airplane weight, or use of airplane ground deceleration devices is different than that used in the preflight calculation." In addition, the FAA stated that "a landing distance assessment should be made under the conditions existing at the time of arrival in order to support a determination of whether conditions exist that may affect the safety of the flight and whether operations should be restricted or suspended."

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[8] The circumstances of the flight 1248 accident (and others) demonstrate that conditions can change between dispatch and arrival and that there is a safety benefit to landing distance assessments at both times.

Existing FAA regulations do not specify either the type of arrival landing distance assessment that should be performed or specify a safety margin that should be applied. The FAA-advocated minimum safety margin of 15 percent for arrival landing distance assessments published in SAFO 06012 is based on historic links to the FAA-mandated additional 15 percent factor for wet/slippery preflight planning requirements and the 15 percent factor embedded in the European Aviation Safety Agency (EASA) and Joint Aviation Authorities (JAA) operational requirements for contaminated runway landing performance. Although during public hearing testimony[9] the FAA stated that the 15 percent landing safety margin has not been substantiated by a specific data collection and evaluation effort, the Safety Board is convinced that a defined landing safety margin is necessary for air carrier operations on contaminated runways. The Board was encouraged when the FAA proposed OpSpec N 8400.C082, which would have required operators of transport-category airplanes to incorporate a 15 percent safety margin in arrival landing distance calculations. The proposed 15 percent safety margin identified in FAA OpSpec N 8400.C082 would have satisfied the intent of Safety Recommendation A-06-16. However, the FAA subsequently sought voluntary operator implementation of such actions through SAFO 06012, compliance with which is voluntary.

Because the FAA has not required actions to address the Board's urgent safety recommendation, flight crews of transport-category airplanes may still be permitted to land in wet, slippery, or contaminated runway conditions, without performing arrival landing distance assessments that incorporate adequate safety margins. As another winter season approaches, the urgent need for such margins becomes more critical. The Safety Board concludes that because landing conditions may change during a flight, preflight landing assessments alone may not be sufficient to ensure safe stopping margins at the time of arrival; arrival landing distance assessments would provide pilots with more accurate information regarding the safety of landings under arrival conditions. Further, the Safety Board concludes that although landing distance assessments incorporating a landing distance safety margin are not required by regulation, they are critical to safe operation of transport-category airplanes on contaminated runways. Therefore, the Safety Board believes that the FAA should require all 14 CFR Part 121, 135, and 91 subpart K operators to accomplish arrival landing distance assessments before every landing based on a standardized methodology involving approved performance data, actual arrival conditions, a means of correlating the airplane's braking ability with runway surface conditions using the most conservative interpretation available, and including a minimum safety margin of 15 percent.

Because the Safety Board recognizes that development of such a standardized methodology will take time, and also recognizes the urgent need for landing distance assessments, the Board recently issued urgent Safety Recommendation A-07-57, resulting from this accident. Urgent Safety Recommendation A-07-57 asked the FAA to (until a standardized methodology as described in the previous recommendation can be developed) "immediately require all 14 CFR Part 121, 135, and 91 subpart K operators to conduct arrival landing distance assessments before every landing based on existing performance data, actual conditions, and incorporating a minimum safety margin of 15 percent." Because the objectives of this recommendation and Safety Recommendation A-06-16 are identical, the Safety Board classified

[9] A public hearing on this accident was held on June 21 and 22, 2006, in Washington, D.C.

A-06-16 “Closed—Unacceptable Action/Superceded.” Because the FAA has had adequate time to require landing distance assessments and implement a landing distance safety margin, but has not, A-06-16 was classified “Open—Unacceptable Response” on May 8, 2007. The superceding safety recommendation will maintain the status of “Open—Unacceptable Response.”

Runway Surface Condition Assessments

The Safety Board has long been concerned about runway surface condition assessment issues.[10] During this investigation, the Safety Board reevaluated the three methods currently used to assess a runway’s surface condition before landing: 1) pilot braking action reports,[11] 2) runway contaminant type and depth observations, and 3) ground surface vehicle friction measurements. The Board notes that all three methods have limitations and that, regardless of the method used, runway surface conditions may vary over time because of changes in precipitation, accumulation, traffic, direct sunlight, temperature, or as a result of runway maintenance/treatment. The Board further notes that no standardized and universally accepted correlation exists to define the relationship between the runway surface condition (using any of the three runway surface assessment methods) and an airplane’s braking ability.

Braking Action Reports

Pilot braking action reports are commonly used by arriving pilots to predict landing runway conditions. However, Safety Board safety recommendation communications, public hearing testimony, and flight 1248 accident evidence indicate that pilot braking action reports are subjective and can vary significantly depending on the reporting pilot’s experience level and the type of airplane in use.

The FAA has frequently acknowledged (most recently in SAFO 06012) that pilot braking action reports are subjective and reflect individual pilot expectations, perceptions, and experiences. Further, braking action reports are sensitive to airplane type and the actual deceleration methods used to slow or stop the airplane. In addition, an arriving pilot may have to interpret mixed pilot braking action reports (for example, fair-to-poor braking action reported on

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[10] As a result of a 1982 special investigation to examine commercial airplane operations on contaminated runways, the Safety Board issued a report titled, *Large Airplane Operations on Contaminated Runways*, which contained, among other recommendations, Safety Recommendation A-82-155, asking that research be conducted to identify reliable and consistent methods for determining runway conditions. Although several industry working groups have convened to address this issue, no consensus has been reached to date regarding the preferred method for doing so, and no significant advances have been developed to eliminate the subjectivity or minimize the variances between reports. In addition, there is no standardized correlation between pilot braking action reports and runway contaminant type and depth, nor is there an internationally recognized and standardized terminology for braking action reports or contaminant type and depth reports. The Board classified Safety Recommendation A-82-155, “Closed—Unacceptable Action.” For more information about this special investigation, see National Transportation Safety Board, *Large Airplane Operations on Contaminated Runways*, Special Investigation Report NTSB/SIR-83/02 (Washington, DC: NTSB, 1983).

[11] As the accident airplane neared MDW, air traffic controllers provided the accident pilots with mixed runway 31C braking action reports indicating that the braking action was good or fair for the first half of runway 31C and poor for the second half.

a landing runway) or conflicting runway condition reports (for example, a pilot braking action report that conflicts with a runway friction measurement).[12]

In SAFO 06012, the FAA defined a reliable braking action report as a braking action report submitted from a turbojet airplane with landing performance capabilities similar to those of the airplane being operated. The FAA recommends in the SAFO that pilots should use all available information and make decisions based on experience and sound judgment; however, the FAA has not yet provided standardized procedures or specific criteria for pilots to use in the development and delivery of braking action reports.

Contaminant Type and Depth

A field report or observation of the type and depth of contaminant on the runway, typically conducted by airport personnel, may also be used to assess the runway surface condition. However, these observations may also be subjective and dependent on the observer's experience and vantage point, the timing of the observation, and rapidly changing conditions. The FAA has not established and defined a standard correlation between an airplane's braking ability and reports of contaminant type and depth.

The Safety Board notes, however, that many airplane manufacturers worldwide (for example, Airbus and Embraer) provide their operators with contaminant type and depth options for landing distance calculations. Further, European agencies (EASA and JAA) require operators to account for contaminated runway conditions and define a minimally acceptable standard that manufacturers can use to correlate contaminant type and depth to airplane landing performance. In practice (and as stated in SAFO 06012), the FAA considers the data developed for showing compliance with EASA and JAA contaminated runway certification or operating requirements acceptable for U.S. arrival landing distance assessments.

Airport Runway Surface Friction Measuring Devices

Runway friction measuring devices were originally developed for use by airports for runway maintenance purposes and were not intended for use in assessing airplane landing performance. Although the FAA funds purchase of these devices for airports and believes that measurements are useful in identifying trends in runway surface condition, FAA representatives have stated that these devices cannot be reliably correlated with airplane performance or pilot braking action reports. Specifically, FAA statements and testimony at the Safety Board's public hearing on this accident indicate that ground surface vehicle friction measurements should not be used to predict airplane stopping performance, in part, because of 1) unresolved variability in equipment design and calibration; 2) changes over time in temperature, sunlight, precipitation, accumulation, and operating traffic; and 3) the results of maintenance and/or treatment of a runway.

[12] A postaccident Safety Board survey of seven operators (not including SWA) indicated that none of them provided their pilots with guidance regarding mixed and/or conflicting braking action or runway condition reports. However, most of the operators surveyed based landing distances on runway contaminant type and depth, not braking action reports.

MDW friction readings were less conservative than the available braking action reports and the postaccident calculated runway 31C surface condition. The runway 31C friction measurement taken at MDW 30 minutes before the accident landing (immediately after the most recent runway cleaning) was 0.67, which a Transport Canada public hearing witness correlated with expected “bare and dry” runway surface condition performance. A measurement taken just after the accident was 0.40, which was considered fairly good according to a public hearing witness from the National Aeronautics and Space Administration. According to Canadian Runway Friction Index (CRFI) data for various runway surface conditions, both measurements (0.67 and 0.40) were within the range of normal values observed with 3 millimeters (mm) or less of loose snow on the runway. Measurements for this surface condition ranged from 0.16 to 0.76. The broad range of measurements possible with a single contaminant demonstrates that this type of runway friction measurement device cannot reliably be used to predict airplane stopping performance under these contaminant conditions (3 mm or less of loose snow).

The Safety Board has previously issued safety recommendations supporting efforts to correlate friction measurement device readings to airplane performance. Boeing does not attempt to correlate runway friction measurements to airplane performance; however, many operators (including SWA) have developed tables that correlate friction measurements to braking action reports. Internationally, Transport Canada provides CRFI tables that correlate ground surface vehicle friction survey measurements to airplane performance for certain contamination conditions; however, use of the CRFI is optional. The Canadian academic community and members of the international research community also support the use of the International Runway Friction Index (IRFI), which is not fully operational or widely supported by the aviation industry. For both the CRFI and the IRFI, runway friction measurements are subject to contaminant type and depth constraints.

Runway Surface Condition Assessments Summary

The Safety Board concludes guidance on braking action and contaminant type and depth reports would assist pilots, air traffic control (ATC), operator dispatch, and airport operations personnel in minimizing the subjectivity and standardization shortcomings of such reports. Further, the Safety Board concludes that using the most conservative interpretation of runway braking action or surface condition reports from mixed or conflicting reports (for example, a fair-to-poor braking action report or a pilot braking action report that conflicts with a runway friction measurement) would increase the landing safety margin. Therefore, the Safety Board believes that the FAA should develop and issue formal guidance regarding standards and guidelines for the development, delivery, and interpretation of runway surface condition reports.

Correlating Runway Surface Condition to Airplane Landing Performance

The Safety Board is concerned that the FAA currently provides no minimally acceptable standard for U.S. operators to use to correlate runway surface condition reports to airplane braking ability.[13] Although a draft Advisory Circular, dated August 1989, proposed a correlation between runway condition (braking action) and an airplane’s braking ability, the FAA never

[13] In Europe, EASA and JAA provide a default relationship between an airplane’s braking ability and contaminant type and depth.

published it. SAFO 06012, issued by the FAA in 2006, also advocated the use of a specific correlation between reported braking action and runway contaminant type and depth to predict turbojet landing/stopping performance but only if the manufacturer-supplied wet or contaminated runway data were unavailable.

Operators need a method to relate any of the three runway surface condition reports and airplane braking ability to determine an airplane's landing performance. However, because the FAA has defined no acceptable correlation standards, manufacturers, operators, and/or third-party suppliers develop their own standards to fulfill their needs.[14] This practice results in variable estimates of an airplane's actual landing performance capability and different landing safety margins being used across even operators of the same make and model airplane. The Safety Board notes that flight crews preparing to land similar airplanes on similar runways, under similar actual conditions should not obtain arrival landing distance results that permit one flight crew to land while the other flight crew cannot, based solely on the operator's choice of how to correlate a runway surface condition report to the airplane's braking ability.

Further, required arrival landing distance assessments should include an additional safety margin to account for variations in actual landing conditions and operational techniques. The current lack of standards in manufacturer-supplied and operator-packaged arrival landing data complicates the validation of both the airplane's basic landing performance capability and adequate safety margins. The Safety Board's investigation of this accident revealed arrival landing distance implementation errors that resulted in latent safety risks at two air carriers. The Safety Board concludes that an adequate safety margin would account for operational variations and uncertainties when factored into arrival landing distance assessments. Further, the Safety Board concludes that establishment of a means of correlating the airplane's braking ability with the runway surface condition would provide a more accurate assessment of the airplane's basic landing performance capability. Therefore, the Safety Board believes that the FAA should establish a minimum standard for Part 121 and 135 operators to use in correlating an airplane's braking ability to braking action reports and runway contaminant type and depth reports for runway surface conditions worse than bare and dry.

Airplane-Based Friction Measurements

The circumstances of this accident demonstrate the need for a method of quantifying the runway surface condition in a more meaningful way to support airplane landing performance calculations.[15] The Safety Board and industry practice of analyzing an airplane's actual landing

[14] The Safety Board notes that operators and third-party suppliers do not generally possess the expertise needed and should not be given license to define (or redefine) basic airplane performance capability. During its investigation of the SWA flight 1248 accident, the Safety Board noted several instances of manufacturer-supplied errors and operator use of outdated or otherwise inaccurate data for their landing performance calculations. Although manufacturers and operators should be allowed to base arrival landing distance assessments on more conservative airplane braking ability correlations, the use of less conservative data should be prohibited.

[15] The Safety Board has previously issued a safety recommendation on this subject (A-82-168), urging the FAA to conduct research to determine whether the characteristic variables of aircraft systems could be correlated to an airplane's stopping ability and related information displayed to pilots for objective braking action reports. The Board did not believe that the FAA's resultant actions were sufficient and subsequently classified Safety Recommendation A-82-168 "Closed—Unacceptable Action."

performance in the aftermath of an accident based on airplane-recorded data demonstrates that runway surface condition and braking effectiveness information can be extracted from recorded data.[16] These practices have shown that if the necessary parameters are recorded, specific calculations and operational procedures performed at lower rollout speeds (for example, wheel brake application for several seconds below 60 knots) can be used to quantify the runway surface condition and estimate the airplane's potential braking ability. Thus, airplane braking coefficient/runway surface condition data derived from one type of landing airplane could be used to estimate another type of airplane's braking ability and landing distance.[17]

During a postaccident meeting in January 2007, Boeing, FAA, SWA, and SWA Pilots Association personnel agreed that this approach to obtain runway surface condition and braking effectiveness data has technical merit. However, the technical and operational feasibility issues associated with an airplane-based friction measurement system have not been evaluated on a test bed or an in-service air carrier airplane to date. A measurement system installed on in-service airplanes could provide runway surface condition data that would surpass information produced by methods currently in use (including ground friction surveys, pilot braking action reports, and type and depth reports), without interfering with traffic flow. Such a system could provide unparalleled runway surface condition quantification and trend information of direct use to pilots, ATC, and airport maintenance.

The Safety Board concludes that development and implementation of an operationally feasible, airplane-based, airplane braking ability/runway surface condition measurement and communication system would provide high value information to subsequent landing airplanes; the benefits of such a system during inclement weather would likely meet or exceed all existing runway surface condition reporting systems, with no resultant interruption to traffic operations. Therefore, the Safety Board believes that the FAA should 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 an airplane during the landing roll. If feasible, the FAA should also require operators of transport-category airplanes to incorporate use of such equipment and related procedures into their operations.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require all 14 *Code of Federal Regulations* Part 121 and 135 operators to ensure that all on board electronic computing devices they use automatically and clearly display critical performance calculation assumptions. (A-07-58)

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[16] Specifically, the Safety Board's airplane performance study for this accident demonstrated the technical feasibility of calculating an airplane's braking ability during the landing roll based on recorded FDR data (including accelerometer, attitude, speed, control input, control surface position, deceleration device usage, and air/ground logic parameters), the airplane configuration, and existing airplane simulation models.

[17] The airplane braking coefficient report from the preceding airplane would be used to perform a rational arrival assessment for the trailing airplane, after correcting for known airplane type, loading, configuration, braked wheel configuration, and antiskid efficiency differences.

Require all 14 *Code of Federal Regulations* Part 121 and 135 operators to provide clear guidance and training to pilots and dispatchers regarding company policy on surface condition and braking action reports and the assumptions affecting landing distance/stopping margin calculations, to include use of airplane ground deceleration devices, wind conditions and limits, air distance, and safety margins. (A-07-59)

Require all 14 *Code of Federal Regulations* Part 121 and 135 operators of thrust reverser-equipped airplanes to incorporate a procedure requiring the non-flying (monitoring) pilot to check and confirm the thrust reverser status immediately after touchdown on all landings. (A-07-60)

Require all 14 *Code of Federal Regulations* Part 121, 135, and 91 subpart K operators to accomplish arrival landing distance assessments before every landing based on a standardized methodology involving approved performance data, actual arrival conditions, a means of correlating the airplane's braking ability with runway surface conditions using the most conservative interpretation available, and including a minimum safety margin of 15 percent. (A-07-61)

Develop and issue formal guidance regarding standards and guidelines for the development, delivery, and interpretation of runway surface condition reports. (A-07-62)

Establish a minimum standard for 14 *Code of Federal Regulations* Part 121 and 135 operators to use in correlating an airplane's braking ability to braking action reports and runway contaminant type and depth reports for runway surface conditions worse than bare and dry. (A-07-63)

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. If feasible, require operators of transport-category airplanes to incorporate use of such equipment and related procedures into their operations. (A-07-64)

Chairman ROSENKER, Vice Chairman SUMWALT, and Members HERSMAN, HIGGINS, and CHEALANDER concurred with these recommendations.

[*Original Signed*]

By: Mark V. Rosenker
Chairman