National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: March 8, 2005

In reply refer to: A-05-03 through -07

Honorable Marion C. Blakey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On March 12, 2003, the tail of Singapore Airlines flight SQ286, a Boeing 747-412, struck the runway and incurred substantial damage during the takeoff rotation at Auckland International Airport in New Zealand. The airplane was fully loaded with fuel, 369 passengers, 17 cabin crewmembers and 3 flight crewmembers (a captain and 2 first officers) for an approximately 9-hour flight from Auckland to Singapore. The flight crew declared an emergency during the airplane's initial climb and returned the airplane to Auckland where an overweight landing was completed. No injuries to the passengers or crew were reported.

The New Zealand Transport Accident Investigation Commission (TAIC) investigated the accident[1] and concluded in its final report that the accident was caused by erroneously low takeoff reference speeds being entered into the airplane's Honeywell flight management system (FMS)[2] based on a takeoff weight transcription error committed by the flight crew. Before the flight, the captain reviewed the flight dispatch paperwork, which included the airplane's zero fuel weight[3] and takeoff gross weight.[4] As the captain read the airplane information from the dispatch paperwork, the first officer, who was responsible for crosschecking the flight dispatch

[1] In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the National Transportation Safety Board participated in this investigation as the U.S. accredited representative for the State of Manufacture.

[2] Honeywell also manufactures FMS computers installed on Boeing 717, 737, 757, 767, 777, MD-80, MD-90, MD-10, and MD-11 model airplanes.

[3] Zero fuel weight is an airplane's total weight without fuel on board.

[4] Airplane gross weight is the entire weight of the airplane, including fuel, passengers, and luggage. The airplane's takeoff gross weight is the gross weight at the beginning of takeoff and is used as the basis for determining takeoff reference speeds.

calculations, transcribed the information onto a reference card used by the airline for pertinent takeoff information for the flight. The captain read a takeoff gross weight of 347.4 tonnes[5] from the flight dispatch paperwork. However, the first officer incorrectly wrote 247.4 tonnes, thus introducing a calculation error of 100 tonnes. The first officer then used an airport analysis chart to independently determine a takeoff rotation speed, or V_r,[6] of 130 knots based on the incorrect takeoff gross weight. At the airplane's actual takeoff gross weight of 347.4 tonnes, the takeoff rotation speed, as determined by the FMS, was 163 knots.

The first officer then wrote the takeoff speeds on the reference card and handed the card to the captain. The captain checked the fuel weight on the reference card against the fuel weight determined by the airplane's onboard fuel quantity system. The captain also confirmed the takeoff gross weight from the dispatch paperwork against the FMS-calculated takeoff gross weight but did not check the takeoff gross weight on the reference card against the takeoff gross weight from either the FMS or flight dispatch paperwork. The captain then entered the erroneous takeoff speeds from the reference card into the airplane's FMS computer, which did not challenge the validity of the new speeds. During the takeoff roll, the flight crew rotated the airplane at 130 knots, which was 33 knots less than the correct airplane rotation speed. (Table 1 shows actual and flight crew-calculated values for flight SQ286). Neither of the other flight crewmembers detected the first officer's transcription error.

Table 1. Actual and Flight Crew-Calculated Values for Singapore Airlines Flight SQ286

Item	Actual Value	Flight Crew-Calculated Value
Takeoff Gross Weight	347.4 tonnes	247.4 tonnes
Takeoff Rotation Speed (V_r)	163 knots	130 knots

A similar FMS-related accident occurred on November 11, 1998, involving Delta Air Lines flight 51, a McDonnell Douglas MD-11, N801DE, which experienced a tailstrike while landing on runway 10R at Portland International Airport, Portland, Oregon. Visual meteorological conditions prevailed for the 14 *Code of Federal Regulations* (CFR) Part 121 scheduled passenger flight, and an instrument flight plan had been filed. No injuries to the 11 crewmembers or 113 passengers were reported, but the aircraft sustained substantial damage.[7]

The Safety Board determined that the probable cause of this accident was "[t]he flight crew's entry of an incorrect weight figure in the [Honeywell] flight management system (FMS) computer, resulting in the approach being flown at an improper (low) V_{ref} speed and an excessively nose-high attitude through the landing flare." Delta's flight dispatch paperwork

[5] One tonne equals approximately 2,205 pounds.

[6] V_r, the airplane rotation speed, is the airspeed at which the pilot flying starts to rotate the airplane.

[7] The description of this accident, SEA99LA014, can be found on the National Transportation Safety Board's Web site at <http://www.ntsb.gov>.

listed the airplane's zero fuel weight as 359,659 pounds, a takeoff fuel weight of 103,000 pounds, a calculated fuel burn of 68,700 pounds, and a gross weight at landing of about 394,000 pounds; however, the airplane's flight data recorder (FDR) data showed that the FMS erroneously determined the gross weight at landing to be 295,000 pounds. The Board's investigation determined that this discrepancy likely occurred as a result of the flight crew either 1) entering the zero fuel weight in the FMS computer's gross weight field or 2) entering a zero fuel weight that was 100,000 pounds less than the airplane's actual weight. Despite the erroneous weight value entered into the FMS, the flight crew accomplished the takeoff using reference speeds related to the airplane's actual weight. This rotation airspeed correlated to the speed shown on the flight dispatch paperwork. The investigation determined that the flight crew most likely modified the FMS-derived reference speeds for takeoff.

Based on the incorrect landing weight, the FMS calculated an approach speed of 132 knots. The flight crew flew the approach at an airspeed of 136 knots,[8] which was 15 knots lower than the approach speed needed for the actual gross weight at landing of 394,000 pounds. (Table 2 shows actual and FMS-calculated values based on the flight crew's data entry error for flight 51). To maintain the reduced airspeed, the flight crew flew the approach at an 8º aircraft-nose-up pitch attitude instead of a typical 3º to 4º pitch attitude. During the airplane's flare for landing, the FDR recorded a maximum pitch attitude of 10.9º. According to the operator, "tail clearance tolerances are minimal" while landing at this speed and attitude.

Table 2. Actual and FMS-Calculated Values for Delta Air Lines Flight 51

Item	Actual Value	FMS-Calculated Value
Aircraft Zero Fuel Weight	359,659 lbs	Not Recorded
Aircraft Total Fuel Weight at Takeoff	103,000 lbs	103,000 lbs
Aircraft Gross Weight at Takeoff	462,000 lbs	362,720 lbs
Aircraft Gross Weight at Landing	394,000 lbs	295,000 lbs
Landing Approach Reference Airspeed	151 knots	132 knots

In 2000, Boeing published two technical bulletins[9] and one magazine article[10] to alert operators about the hazards of incorrect FMS entries after several operators reported erroneous

[8] The Safety Board's investigation also considered that the flight crew may have selected an approach reference speed by using flipcharts. Delta Air Lines reported that the minimum landing weight indicated in its MD-11 flipcharts was 320,000 pounds. At this landing weight and with 35º flaps, the MD-11 flipcharts indicated an approach reference speed of 132 knots.

[9] On March 31, 2000, Boeing issued a flight operations technical bulletin for operators of the 737, 757, 767, 777, and 747-400 titled "Inadvertent Entry of Zero Fuel Weight (ZFW) into the Gross Weight (GW) Line of the FMC flight management computer." On June 8, 2000, Boeing issued a flight operations bulletin for all B-717, MD-90, MD-10, MD-11, and FMS-equipped MD-80 airplanes.

[10] The July 2000 issue of *Boeing Airliner* magazine included the article "Erroneous Takeoff Reference Speeds."

takeoff reference speeds that were calculated from incorrect gross weights. The bulletins identified the type of FMS errors that had occurred and discussed FMS operation, airplane weights, and FMS-generated takeoff speeds. The bulletins also focused on the inadvertent entry of the zero fuel weight value into the gross weight field in the FMS. The information emphasized that the most effective solution would be for operators to adopt a policy that flight crews enter only the zero fuel weight into the FMS and permit the system to then compute takeoff gross weight by adding the fuel weight measured from the fuel quantity gauging system.

The accident involving Singapore Airlines flight SQ286 demonstrates that FMS-related events are continuing to occur despite Boeing's efforts to educate operators about the dangers of incorrect FMS entries. In its final report regarding this accident, the TAIC expressed concern that, because the FMS is not designed to detect and annunciate incorrect entries, it is incumbent on the flight crew to detect any such errors. In this case, the FMS allowed the takeoff reference speeds to be changed to values significantly lower than those it had derived even though the takeoff gross weight had not been changed correspondingly. The TAIC recommended in its report that, because takeoff gross weight is used as a basis for takeoff reference speeds, Boeing should "implement a[n] FMS software change on all various Boeing aircraft models that ensures any entries (such as V speeds and gross weight) that are mismatched by a small percentage are either challenged or prevented."

In a November 17, 2003, response to the TAIC, Boeing indicated that it would "continue to examine the safety recommendation in the context of the broader issue regarding incorrect takeoff speeds" and "will determine whether changes to existing FMS installation may be warranted." Boeing noted its belief that incorporating a change to the FMS to prevent significant changes of takeoff reference speeds would not prevent most accidents resulting from incorrect reference speeds because most of these accidents were the result of incorrect weight entries. Boeing also stated that an FMS warning based on differences in takeoff reference speed would result in nuisance warnings to the flight crew because, in some situations, manually calculated takeoff reference speeds may differ from FMS-calculated speeds by a large amount and yet still be correct. Boeing noted that the speeds calculated by the FMS do not take into account factors such as runway length, runway friction conditions, or improved-climb techniques, which may be considered when calculations are performed manually.[11] Therefore, manually calculated takeoff reference speeds can vary significantly from FMS-calculated values. Boeing, in its response to the TAIC, continued:

> We are, however, exploring the possibility of checking that the manually entered [rotation reference speed, or V_r] is not significantly lower than the FMS-calculated value. It appears that narrowing the check in this manner [to monitor only V_r rather than all entries, as recommended by the TAIC] may produce the intended safety benefit while avoiding some of the problems mentioned above.[12]

[11] The FMS calculates speeds based on a balanced field length, which is the runway length that accommodates both the accelerate-go distance and the accelerate-stop distance.

[12] In June 2004, the Safety Board asked Boeing if there were any updates to the information contained in the November 2003 response to the TAIC. Boeing indicated that there were none.

The Safety Board does not believe that further study is necessary to incorporate changes to the FMS that would prevent changing a takeoff reference speed to a value that would impede the airplane's ability to safely take off. If such FMS logic were installed on flight SQ286, the FMS would have prevented the flight crew from altering the rotation speed to a value 33 knots below the correct value. The Board also disagrees that modifying the FMS software as suggested would result in nuisance alerts because, at the least, the alerts would prompt a flight crew to confirm an entry and, more importantly, would alert a crew to a potential problem. Because Honeywell manufactures FMSs that are installed on numerous airplane models and likely allow similar data entry errors, the Safety Board believes that the Federal Aviation Administration (FAA) should require Honeywell to modify its FMS software to annunciate warnings to the flight crew when a takeoff reference speed is changed by a value that would impede the airplane's ability to safely take off and require all operators of airplanes with Honeywell FMSs to incorporate this software modification.

The circumstances of the accident involving Delta Air Lines flight 51 demonstrate another deficiency with the Honeywell FMS. Although the system has provisions to flag gross weight or zero fuel weight values that are less than a minimum value and will also flag input weight values greater than the maximum takeoff gross weight, it has no method for checking the validity of input weight values that fall between these minimum and maximum values. For example, as was mentioned previously, the FMS determined an incorrect gross weight at landing of 295,000 pounds based on the flight crew's incorrect airplane weight entry before takeoff and a calculated fuel burn of 68,700 pounds during the flight. According to Delta's flight dispatch paperwork for flight 51, the airplane's operating empty weight[13] was 295,875 pounds and its zero fuel weight was 359,659 pounds. Therefore, the FMS indicated a landing weight that was less than both the airplane's zero fuel weight and operating empty weight, which the system and the flight crew failed to recognize.

One method to verify the validity of weight inputs would be to compare the input gross weight to the airplane's operating empty weight, which airlines typically determine at regular intervals by weighing the airplane. This value may be used for months or even years because an airplane's empty weight does not change significantly over time. If the airplane's operating empty weight were entered and retained by the FMS at regular maintenance intervals, the FMS could perform rudimentary arithmetic error-checks of weight entries. Such a software modification would provide the added benefit that the FMS could not derive an approach reference airspeed based on landing weights that are less than the airplane's zero fuel weight or operating empty weight. Therefore, the Safety Board believes that the FAA should require Honeywell to modify its FMS software to prevent entry of airplane weights that would result in landing weights below zero fuel weight or operating empty weight, and require all operators of airplanes with Honeywell FMSs to incorporate this software modification.

[13] Airplane operating empty weight is the weight of the airplane without fuel, passengers, cargo, and baggage and is used by the airlines for flight dispatch and aircraft performance calculations.

In the publications that Boeing issued to operators in 2000 informing them of methods to reduce the risk of erroneous takeoff reference speeds, Boeing offered an option that it had developed of using an uplink from the aircraft communications and reporting system to display takeoff weight data on the FMS rather than the flight crew typing in this information. Boeing also indicated that it was investigating an option to inhibit any entry into the gross weight field, which would eliminate the possibility of flight crews erroneously entering zero fuel weight into the gross weight field. The Safety Board considers either of these suggestions to be viable methods of ensuring the integrity of gross weight values. Therefore, the Board believes that the FAA should require Honeywell to modify its FMS software either to inhibit manual entries in the gross weight field or to allow the takeoff gross weight to be uplinked directly into the FMS, and require operators of airplanes with Honeywell FMSs to incorporate this software modification.

Because the investigations of both of the events discussed in this letter have identified error-checking deficiencies in Honeywell's FMS software, the Safety Board is concerned that additional methods for entry errors may exist that have not been detected. Airframe manufacturers, operators, and the FAA may have knowledge of additional FMS erroneous data entry scenarios that could result in unsafe operating conditions. Therefore, the Safety Board believes that the FAA should require Honeywell to conduct a study of its FMS computers to identify any additional improvements that may be necessary for error checking and confirming that the entered takeoff and landing performance information is correct and reasonable.

Finally, because FMSs manufactured by other companies have designs similar to those manufactured by Honeywell, the Safety Board is concerned that they may be susceptible to the same types of data entry errors. Therefore, the Board believes that the FAA should require companies other than Honeywell that manufacture FMSs that are installed on 14 CFR Part 25 airplanes to study their FMS computers to identify any improvements that may be necessary for error checking and confirming that the entered takeoff and landing performance information is correct and reasonable.

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

> Require Honeywell to modify its flight management system (FMS) software to annunciate warnings to the flight crew when a takeoff reference speed is changed by a value that would impede the airplane's ability to safely take off, and require all operators of airplanes with Honeywell FMS computers to incorporate this software modification. (A-05-03)
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> Require Honeywell to modify its flight management system (FMS) software to prevent entry of airplane weights that would result in landing weights below zero fuel weight or operating empty weight, and require all operators of airplanes with Honeywell FMS computers to incorporate this software modification. (A-05-04)
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> Require Honeywell to modify its flight management system (FMS) software either to inhibit manual entries in the gross weight field or to allow the takeoff gross weight to be uplinked directly into the FMS, and require operators of

airplanes with Honeywell FMSs to incorporate this software modification. (A-05-05)

Require Honeywell to conduct a study of its flight management system computers to identify any additional improvements that may be necessary for error checking and confirming that the entered takeoff and landing performance information is correct and reasonable. (A-05-06)

Require companies other than Honeywell that manufacture flight management systems (FMS) that are installed on 14 *Code of Federal Regulations* Part 25 airplanes to study their FMS computers to identify any improvements that may be necessary for error checking and confirming that the entered takeoff and landing performance information is correct and reasonable. (A-05-07)

Chairman ENGLEMAN CONNERS, Vice Chairman ROSENKER, and Members CARMODY, HEALING, and HERSMAN concurred with these recommendations.

Sincerely,

Original Signed

Ellen Engleman Conners
Chairman