National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 25, 2000

In reply refer to: A-00-92 through -103

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

In this letter, the National Transportation Safety Board recommends that the Federal Aviation Administration (FAA) take action to address the following safety issues: air carrier pilot training in landing techniques and bounced landing recovery, training tools and policies that promote proactive decision-making to go around if an approach is unstabilized, the use of on board computers to determine the required runway length for landing, MD-11 handling characteristics and structural integrity requirements, and hard landing inspection requirements. The Safety Board identified these issues in its investigation of the 1997 accident involving Federal Express flight 14 in Newark, New Jersey. This letter summarizes the Board's rationale for issuing these recommendations.

On July 31, 1997, about 0132 eastern daylight time,[1] a McDonnell Douglas MD-11,[2] N611FE, operated by Federal Express, Inc., (FedEx) as flight 14, crashed while landing on runway 22R at Newark International Airport (EWR). The regularly scheduled cargo flight originated in Singapore on July 30 with intermediate stops in Penang, Malaysia; Taipei, Taiwan; and Anchorage, Alaska. The flight from Anchorage International Airport (ANC), Anchorage, Alaska, to EWR was conducted on an instrument flight rules flight plan and operated under provisions of 14 Code of Federal Regulations (CFR) Part 121. On board were the captain and first officer, who had taken over the flight in Anchorage for the final leg to EWR, one jumpseat passenger, and two cabin passengers.[3] All five occupants received minor injuries in the crash and

[1] Unless otherwise indicated, all times are eastern daylight time based on a 24-hour clock.

[2] Boeing Commercial Airplane Group acquired the holdings of Douglas Aircraft Company and McDonnell Douglas in 1997. The MD-11 was developed by McDonnell Douglas as a follow-on to the DC-10, which first flew in 1970. According to *Jane's All the World's Aircraft*, the MD-11, which was granted a type certificate on November 8, 1990, has, among many design changes, a longer fuselage, a redesigned tailplane, winglets above and below the wingtips, and advanced cockpit instrumentation.

[3] The jumpseat passenger was a pilot for another airline, and the two cabin passengers were FedEx employees.

during subsequent egress through a cockpit window. The airplane was destroyed by impact and a postcrash fire.[4]

The Safety Board determined that the probable cause of this accident was the captain's overcontrol of the airplane during the landing and his failure to execute a go-around from a destabilized flare. Contributing to the accident was the captain's concern with touching down early to ensure adequate stopping distance.

Airplane Performance During the Approach and Landing

During the approach, the airplane was configured for landing, with flaps set at 50°. The captain disconnected the autopilot as the airplane descended through 1,200 feet, and the autothrottles remained engaged. According to flight crew statements and flight data recorder (FDR) data, the airplane maintained the approach speed of about 158 knots (consistent with the target approach speed specified by FedEx, V_{ref}+5 knots or 157 knots), at a stable 800 feet per minute (fpm) descent rate, and on the instrument landing system (ILS) localizer and glideslope for runway 22R[5] until the landing flare. The average pitch attitude of 3° airplane nose up was consistent with MD-11 flight manual data for descending on the ILS glideslope's 3° flightpath angle, given the airplane's weight, center of gravity (c.g.), and flaps-50 configuration. The captain and the first officer also stated that the approach was routine until just before touchdown. Thus, on the basis of flight crew statements and airplane performance data, the Safety Board concludes that the airplane's approach before the landing flare was stabilized.

FDR data indicated that control inputs consistent with the start of flare occurred at about 37 feet radio altitude. Engine thrust was also decreasing about this time.[6] About 1.5 seconds after the start of the flare and 2 seconds before the first of two touchdowns, pitch attitude peaked at 5° nose up. The radio altitude was 17 feet. This portion of the flare maneuver was consistent with FedEx MD-11 flight manual guidance, which called for a "smooth 2.5 degree flare" to be initiated between 30 and 40 feet radio altitude. Thus, the Safety Board concludes that the captain's execution of the beginning of the flare maneuver was normal and not a factor in the accident.

As pitch attitude peaked about 2 seconds before the first touchdown, the elevator started deflecting from about 12° nose up to near 0°, and the airplane's pitch attitude began decreasing slightly in response to the nose-down elevator input. Further, about 1 second before ground contact, elevator deflection reversed to a nose-up elevator deflection of 26° (from about neutral elevator to about 70 percent of maximum nose-up elevator), and throttle resolver angles (TRA)[7]

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[4] For more detailed information, see National Transportation Safety Board. 2000. *Crash During Landing, Federal Express, Inc., McDonnell Douglas MD-11, N611FE, Newark International Airport, Newark, New Jersey, July 31, 1997*. Aircraft Accident Report NTSB/AAR-00/02. Washington, D.C.

[5] The runway was equipped with a Category I ILS, which included an outer marker beacon but no middle or inner markers. The glideslope was set at a standard 3° angle.

[6] With the MD-11 autothrottle system engaged and flaps extended to greater than 31.5°, the throttles are automatically driven to the idle stop when the radio altitude decreases through 50 feet.

[7] The MD-11 is equipped with an electronic automated engine power control system. The throttle resolver levers on the cockpit's power control pedestal are linked to a throttle switch and cam assembly that sends electronic

increased from about 40° to 70° (from near flight idle to near takeoff thrust). A small right-wing-down aileron input (4° to 5°) followed. The nose-up, throttle-up, and right-wing-down control inputs were initiated as the airplane was descending through 7 feet radio altitude. Pitch attitude and vertical acceleration had just begun to respond when the airplane contacted the ground in the first of two touchdowns. Vertical speed at the first touchdown was about 7.6 feet per second (fps),[8] and vertical acceleration peaked at 1.67 g. The nose-up elevator and throttle inputs also peaked about the time of the first touchdown.

Within 1/2 second after the first touchdown, the captain initiated a rapid nose-down elevator input. The total elevator travel was about 40° (changing from about 70 percent of maximum nose-up elevator to about 67 percent of maximum nose-down elevator in less than 1 second). Despite the initiation of the large and rapid nose-down elevator input, the airplane began to lift off the runway as a result of landing gear strut and tire compression loads and the still-increasing pitch attitude, thrust, and airspeed. In addition, wing lift was not degraded upon touchdown because the spoilers did not deploy.[9]

After the initial touchdown, the airplane was airborne for about 2 seconds.[10] During the first second, while airborne, the elevator remained about 67 percent nose down. In the next second, a large and rapid nose-up elevator input occurred (from 67 percent nose down to 60 percent nose up), accompanied by nose left rudder and right-wing-down aileron inputs.[11]

About 3/4 second before the second touchdown, as the airplane was peaking at a height of 5 feet agl, lift had decreased to about 0.6 g. The pitch attitude was about 2° nose-up and decreasing rapidly. The elevator was about 15° nose down, although it was moving rapidly toward a nose-up position. Given the nose-down elevator position at that point in the bounce, there were probably no additional crew actions that could have been taken to prevent a hard impact with the runway.

The airplane touched down for the second time as vertical acceleration was decreasing through 0.5 g. The second touchdown occurred at a roll angle of 9.5° right wing down, a roll rate

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signals, based on power setting, to a full authority digital engine control unit located on the engine. Throttle resolver (lever) degree angles represent the total travel of the throttle lever from the "forward limit stop" (of about 85°), to the idle aft limit (of about 41°), to just below the "reverse stop" (of 7.7°). Forward travel of the throttles is limited by an overboost stop (about 81°). This stop has a detent that allows continued forward movement of the throttles when they are pushed with a strong force. Among other things, this extra forward travel causes autothrottle disengagement.

[8] This value is the vertical speed at the right main landing gear (MLG) and includes 6.6 fps vertical speed at the c.g. plus 1.0 fps vertical speed at the right MLG because of nose-up pitch rate and right-wing-down roll rate.

[9] Ground spoilers on the accident airplane did not deploy after touchdown because the TRA was greater than 49°. The No. 2 engine throttle lever mechanically prevents ground spoiler deployment if its position is greater than 44° to 49° (about 1.05 inches) forward of idle and knocks down extended spoilers if the No. 2 engine throttle lever exceeds this range. Ground spoilers, or speed brakes, are hinged or otherwise moveable surfaces on the upper rear surface of a wing that reduce lift and increase drag when extended.

[10] The time interval between the first touchdown and the second was about 3 seconds. During those 3 seconds, the airplane was on the ground with the struts stroking and tires compressing for about 1 second and was airborne for about 2 seconds.

[11] The Safety Board could not determine why the captain commanded right-wing-down aileron and left rudder deflection before the second touchdown.

of approximately 7° per second right wing down, and a pitch attitude of minus 0.7°. Peak vertical speed at the right main landing gear (MLG) was approximately 13.5 fps. The right wing failed at impact.

The captain's actions during the 5 seconds preceding the second touchdown established the conditions that led to the right wing failure. When the captain rapidly moved the elevators to near neutral instead of maintaining nose-up elevator and continuing the flare (2 seconds before first touchdown), he destabilized the flare and established a greater sink rate. The large nose-up elevator and thrust inputs that the captain made with only 1 second remaining before touchdown were his reaction to the sink rate and an attempt to prevent a hard landing. From that moment on, evidence indicates that all of the captain's control inputs were too late and too large to achieve the desired effect. Although he began nose-down inputs at about the time of the first touchdown, the airplane had bounced back into the air by the time he had pushed almost all the way forward on the control column. This large nose-down input, in turn, established a very high sink rate and low g load at the time of the second touchdown. The captain's final, large nose-up inputs were made too late to soften the impact. The airplane touched down with enough energy and at a sufficiently high roll angle to bottom the right MLG strut and break the right wing.

All available data indicate that the airplane's aerodynamic performance and flight control functionality were normal until after the second touchdown. Thus, the Safety Board concludes that the accident airplane performed normally in response to the captain's flight control inputs until after the second touchdown.

Flight Crew Factors During the Approach and Landing

During the approach briefing, the first officer and the captain discussed the stopping distance available on runway 22R for the airplane's weight and landing configuration. During that discussion, they expressed concerns about the approximate landing distance and the length of the runway, which they had derived from the airport performance laptop computer (APLC).[12] Additionally, during the approach, the flight crew indicated that they were aware of the inoperative No. 1 engine thrust reverser,[13] which would have resulted in a slight reduction in deceleration capability after landing.[14] The flight crew was also aware of three recent events recorded in the airplane's maintenance log in which the airplane's autobrakes[15] had failed to arm at

[12] As an airplane approaches the landing airport, pilots enter several parameters (for example, weather information and airplane weight) into the APLC, which generates landing data, including the approximate landing distances for usable runways at a selected airport.

[13] A jet engine thrust reverser deflects airflow in the forward direction to help reduce the airplane's speed after touchdown. Maintenance personnel at ANC deactivated the No. 1 thrust reverser after finding a delaminated door on it. Flight 14's departure with an inoperative thrust reverser was approved under provisions of the airplane's minimum equipment list (MEL). The MEL is developed by each operator of an aircraft and must be equivalent to or more conservative than the master MEL, which is developed by the manufacturer and approved by the FAA.

[14] Although the flight crew may have been concerned about the reduction in deceleration capability, the inoperative thrust reverser did not increase the runway length requirement for the accident landing above that shown in the APLC because the deceleration effects of the thrust reversers are not used in calculating the distances required for landing.

[15] The MD-11's autobrakes, or automatic brake system (ABS), automatically apply brakes during landing and rejected takeoff. The takeoff mode is armed by selecting "T.O. [takeoff] with the AUTO BRAKE selector,"

takeoff or failed to work at landing. Although maintenance personnel had checked the system after each reported failure and determined it was functioning properly, the captain told Safety Board investigators that he discussed the reliability of the autobrake system with the first officer before takeoff from ANC. The captain told investigators that the autobrakes remained armed during the departure from ANC. However, he kept the autobrake problem in mind when planning for the landing at EWR, adding that he planned to land the airplane at the start of the runway and wanted to ensure that the airplane would not float during the landing flare.

Thus, on the basis of the flight crew's comments during the approach about the relatively short runway length, the inoperative thrust reverser, the questionable reliability of the autobrake system, and the perceived need to land at the beginning of the runway, the Safety Board concludes that the captain was concerned about the airplane's touchdown location on runway 22R and intended to take measures during the landing to achieve an early touchdown and minimize the length of the rollout on the runway after touchdown.

The Safety Board examined the captain's 12° nose-down elevator input at 17 feet radio altitude to determine if it was consistent with FedEx guidance for landing the MD-11. The Board's review of FedEx's MD-11 landing guidance found only one technique that promotes the use of nose-down elevator between the initiation of flare and touchdown. Specifically, the FedEx MD-11 "advanced technique" for landing recommends that "elevator back pressure…be relaxed" about 10 feet before touchdown (to achieve a 1° decrease in pitch attitude). However, the captain's nose-down elevator input, which moved the elevator from 12° nose-up to about the neutral position, was very rapid and much greater than is required for the maneuver. Further, the captain began his nose-down input about 1 second before the airplane reached 10 feet radio altitude, the aural annunciation of which should have served as the cue for such a pitch reduction if it had been related to the FedEx "advanced" landing technique. Thus, the Safety Board concludes that the captain's nose-down elevator input beginning at 17 feet radio altitude was not consistent with FedEx guidance for landing the MD-11. Further, the Safety Board concludes that the captain's nose-down elevator input at 17 feet radio altitude (2 seconds before the first touchdown) was consistent with an attempt to control the point of touchdown given his concerns about the runway length.

The captain and the first officer told Safety Board investigators that they felt the airplane's sink rate increase shortly before the airplane touched down. They stated that these were "seat of the pants" feelings and were not based on observed indications on cockpit instruments. FDR data indicated that after the captain made the nose-down elevator input at 17 feet radio altitude, a small increase in sink rate and decrease in vertical acceleration occurred. The decreased vertical acceleration and increased nose-down pitch rate could have led to sensations of sink consistent with the pilots' descriptions.

With just more than 1 second remaining before touchdown, the captain had the following options: accept the sink rate and subsequent hard landing, attempt to salvage the landing with last-second thrust and pitch adjustments, or execute a go-around. FDR data and postaccident

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according to the MD-11 flight crew operating manual (FCOM). The ABS landing mode is armed after the gear is down.

interviews show that the captain chose to try to salvage the landing with last-second thrust and pitch adjustments. Thus, the Safety Board concludes that the captain made a nearly full nose-up elevator input and a large throttle increase to compensate for the increased sink rate caused by his previous nose-down input.

The FedEx MD-11 flight manual recommends that a "constant pitch attitude be maintained from 10 feet radio altitude until touchdown." However, this guidance presupposes a stabilized approach and flare leading up to 10 feet radio altitude. In contrast, because the captain had destabilized the flare 1 second earlier, he perceived a need to arrest the resulting sink rate with additional thrust and nose-up pitch.

FedEx's high sink rate and bounce recovery training recommends establishing a 7.5° pitch attitude and "arresting the sink rate with thrust" as a prelude to either landing with a high sink rate, re-landing the airplane after a bounce, or executing a low-level go-around. However, FedEx's MD-11 tailstrike awareness training also cautioned that "quickly adding up elevator" near the ground should be avoided because it can result in increased nose-up pitch rate at touchdown, increased downward vertical speed at the MLG, a hard landing, and tailstrike. To gain a better understanding of this training and its relevance to the captain's actions, Safety Board investigators participated in FedEx classroom and simulator training for high sink rate and bounce recovery, as well as for tailstrike avoidance. This experience demonstrated to investigators that the timing and large magnitude of the captain's nose-up elevator input just before the first touchdown were inconsistent with FedEx's MD-11 high sink rate recovery and tailstrike awareness training.

The captain's large, nose-down elevator input began within 1/2 second of the first touchdown. Based on the sequence and timing of the events, this nose-down elevator input was the captain's response to the airplane's rapid nose-up pitching motion, which began in the second before touchdown as a result of the captain's immediately preceding large nose-up elevator input, and/or his attempt to rapidly land the nosewheel and begin braking immediately after touchdown. After the airplane touched down hard and bounced, the captain continued his nose-down input while the airplane continued to pitch up.

A large nose-up pitch rate and high pitch attitude at touchdown would have introduced several factors that may have contributed to the captain's subsequent large nose-down elevator input. First, MD-11 pilots are taught in training that nose-up pitch rate and high pitch attitude at touchdown are factors that lead to tailstrike. This consideration may have caused the captain to believe he should apply additional nose-down elevator to the amount that he normally applies after touchdown to counter the MD-11's characteristic nose-up pitching moment following ground spoiler deployment.[16] Second, as demonstrated by his statements on the CVR and during postaccident interviews, the captain would have continued to be concerned about the available runway length; the rapidly increasing pitch attitude just before and during the first touchdown would have increased the probability of a floating flare, which, in turn, would have decreased the amount of runway available to bring the airplane to a stop. Therefore, the Safety Board concludes

[16] MD-11 pilots are taught and the MD-11 FCOM advises that ground spoiler deployment at touchdown creates a nose-up pitching moment that must be counteracted with pilot-induced nose-down elevator inputs. This technique is referred to in the MD-11 FCOM and operator training as "flying the nose to the runway."

that the captain's full nose-down elevator control input at the time of the first touchdown was consistent with his continued concerns to avoid a long landing and his desire to avoid a tailstrike.

Summary of the Captain's Elevator Control Inputs

Considering the captain's three significant elevator control inputs in sequence, it is apparent that after the first destabilization of the landing flare (from the captain's nose-down input at 17 feet agl), each of the succeeding nose-up/nose-down elevator inputs resulted from the captain's attempt to correct for the immediately preceding control input. His perception of a short runway and the need to constrain the pitch attitude within a very limited range (to avoid a tailstrike) would have motivated the captain to rapidly return the airplane to a stable attitude. He attempted to accomplish this goal with the quick application of large elevator inputs; however, this succession of elevator inputs and pitch oscillations rendered the landing attempt increasingly unstable.

Throughout the sequence of increasingly extreme nose-down and nose-up elevator inputs, which were consistent with a "classic" pilot-induced oscillation (PIO),[17] the captain continued to attempt to salvage the landing; however, a go-around executed by the captain at any time through the touchdown and bounce would have prevented the accident. Therefore, the Safety Board concludes that the captain's overcontrol of the elevator during the landing and his failure to execute a go-around from a destabilized flare were causal to the accident.

Further, the Safety Board's examination of the training that FedEx provided its pilots in landing the MD-11 showed that its training was consistent with and, in some respects, exceeded that provided by many other major airlines. On the basis of comparing the captain's control inputs with FedEx's procedures and training for landing the MD-11, the Safety Board concludes that the captain's control inputs during the flare and bounce were not consistent with landing procedures and techniques outlined in the FedEx MD-11 pilot training procedures, McDonnell Douglas flight crew operating manual (FCOM), or with FedEx's MD-11 tailstrike awareness and high sink rate and bounce recovery training.

Enhanced Pilot Training

The Safety Board attempted to determine if a factor in the captain's training history could explain his actions in attempting to control the airplane during the landing and thereafter. The Board notes that the captain received an unsatisfactory evaluation on an upgrade proficiency checkride on October 29, 1996. However, the Board obtained no other evidence that could reflect negatively on the captain's skills. Other than the October 1996 checkride, there was no history of unsatisfactory performance or of disciplinary action in his career at FedEx. There was also no record of accident, incident, or enforcement action in his FAA records. In addition, in the 10 months after the failed checkride, the captain satisfactorily completed a proficiency check and

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[17] PIO in the pitch axis can occur when pilots make large, rapid control inputs in an attempt to quickly achieve desired pitch attitude changes. The airplane reacts to each large pitch control input, but by the time the pilot recognizes this and removes the input, it is too late to avoid an overshoot of the pilot's pitch target. This, in turn, signals the pilot to reverse and enlarge the control input, and a PIO with increasing divergence may result.

two line checks (the last line check was 20 days before the accident). Thus, the Safety Board concludes that the captain had no previously documented skill deficiencies that contributed to this accident.

The captain's failure to properly respond to a destabilized flare and his excessive overcontrol of the airplane, as well as the accumulated evidence from previous air transport landing accidents,[18] indicate that action may be warranted to improve the quality of air carrier training and guidance to pilots in performing safe landings. The circumstances of this and other accidents suggest that, although accidents before or shortly after touchdown are rare, the risk of a future catastrophic accident could be reduced if air carrier pilot training programs devote additional attention to safety issues related to landings. It is particularly important to instill in pilots the orientation to perform a go-around in the event of an unstabilized approach or destabilized landing flare.

Shortly after the Safety Board conducted a special investigation[19] of rejected takeoff accidents in 1990, a joint government-industry task force was formed to study the issue and develop a flight crew training aid. This training aid has led to a reduction in the incidence of rejected takeoff accidents and incidents.[20] The Board notes that other government-industry efforts have produced valuable training tools to avoid and recover from inadvertent encounters with wake vortices, windshear, controlled flight into terrain events, and aircraft upsets.

The Safety Board's review of accidents involving pilots' control handling in the landing phase of flight, including this accident, indicates that a similar training tool development effort should be made for landings. This tool should devote specific attention to proper high sink rate recovery techniques during the landing flare, risks associated with pilot-induced oscillations during the landing, and the hazards associated with overcontrol and premature derotation during a bounced landing.

In 1995, responding to a safety recommendation[21] issued by the Safety Board as a result of its investigation of three Boeing 767 landing accidents as well as incidents involving DC-10s and MD-11s, the FAA issued Flight Standards Information Bulletin for Air Transport (FSAT) 95-06. This document required FAA principal operations inspectors (POI) to ensure that pilot training programs for the Boeing 757/767, DC-10, and MD-11 include a discussion about derotation accidents. Unfortunately, FSAT 95-06 expired in 1996.

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[18] For more detailed information, see sections 1.18.4 through 1.18.7 in Aircraft Accident Report NTSB/AAR-00/02, *Crash During Landing, Federal Express, Inc., McDonnell Douglas MD-11, N611FE, Newark International Airport, Newark, New Jersey, July 31, 1997.*

[19] National Transportation Safety Board. 1990. *Runway Overruns Following High Speed Rejected Takeoffs.* Special Investigation Report NTSB/SIR-90-02. Washington, D.C.

[20] A review of the Safety Board's database of U.S. accidents revealed no fatal overrun events since 1990.

[21] On June 16, 1994, the Safety Board issued Safety Recommendation A-94-119 asking the FAA to "modify initial and recurrent Boeing 757/767 pilot training programs, and other airplane model pilot training programs as deemed appropriate, to include discussion of derotation accidents."

Further, in its submission[22] to the Safety Board on the Newark accident, Boeing advocated expanding traditional approach go-around guidance to instruct that missed approaches be made if the airplane is not stabilized by 500 feet or if approaches involve “large pitch deviations. Board concurs with this suggestion and notes that air carrier pilots’ adoption and use of a proactive go-around philosophy would be a desirable goal for a training tool development effort on this issue.

Following this accident, FedEx added instructional material and guidance on landing gear and wing structural certification to its tailstrike awareness training program. This guidance detailed the effects of vertical acceleration on the MLG and wings and explained the effects of roll and pitch rate on total sink rate. The FedEx training information describes in detail the aerodynamic effects of large nose-down elevator inputs that result in reduced-g touchdowns, which increase the loads that must be absorbed by the MLG.

The Safety Board notes that one of the new FedEx training modules closely describes the acceleration, pitch, and roll factors found in the Newark accident scenario. However, based on discussions with pilots who have flown with several air carriers, the Board is concerned that this information may be lacking in other operators’ training programs and that this lack of landing guidance could contribute to similar landing accidents. Thus, based on its review of air carrier landing accidents, the Safety Board concludes that air carrier pilots’ performance would be improved by additional guidance and training in landing techniques.

Therefore, the Safety Board believes that the FAA should convene a joint government-industry task force composed, at a minimum, of representatives of manufacturers, operators, pilot labor organizations, and the FAA to develop, within 1 year, a pilot training tool to do the following:

(a) Include information about factors that can contribute to structural failures involving the landing gear, wings, and fuselage, such as design sink rate limits; roll angle limits; control inputs’ roll rate; pitch rate; single-gear landings; the effect of decreased lift; and structural loading consequences of bottoming landing gear struts and tires;

(b) Provide a syllabus for simulator training on the execution of stabilized approaches to the landing flare, the identification of unstabilized landing flares, and recovery from these situations, including proper high sink rate recovery techniques during flare to landing, techniques for avoiding and recovering from overcontrol in pitch before touchdown, and techniques for avoiding overcontrol and premature derotation during a bounced landing; and

(c) Promote an orientation toward a proactive go-around.

[22] Boeing's Long Beach Douglas Products Division. Undated. Submission of Proposed Findings for *FedEx Flight 14, MD-11-F, N611FE, Newark, New Jersey, 31 July 1997.*

Landing Distance Calculation Errors

During its investigation, the Safety Board determined that the flight crew misinterpreted the APLC stopping distance data for medium (MED) autobrakes by incorrectly comparing APLC runway data with the landing distance provided on the approach plate for runway 22R. Although there was sufficient stopping distance for a MED autobrake setting, the misinterpretation of the APLC data,[23] among other factors, led the captain to believe that stopping distance would be an issue in the landing. Thus, the Safety Board concludes that the flight crew's calculation error in determining the runway length required for landing influenced the captain's subsequent actions during final approach and landing by creating a sense of urgency to touch down early and initiate maximum braking immediately.

The Safety Board is concerned that two pilots with significant APLC experience at FedEx failed to properly interpret the calculated landing distances and that other experienced flight crews may also be deficient in their operational knowledge of how APLC systems function. The Board notes that following the accident, FedEx expanded the APLC pilot training presentation for all initial and upgrade training and also added it to recurrent flight crew training programs. The Board has learned that several operators have either adopted systems similar to FedEx's APLC system or are considering doing so and that other electronic performance calculators are in use at other operators. Thus, the Safety Board concludes that some flight crewmembers may lack proficiency in the operation of APLCs, or similar airplane performance computing devices, and that confusion about calculated landing distances may result in potentially hazardous miscalculations of available runway distances after touchdown. Therefore, the Safety Board believes that the FAA should require POIs assigned to Part 121 carriers that use auxiliary performance computers to review and ensure the adequacy of training and procedures regarding the use of this equipment and the interpretation of the data generated, including landing distance data.

MD-11 Handling Characteristics and Flight Control System Design

MD-11 Nose-Up Pitching Moment Because of Ground Spoiler Deployment

The MD-11's known tendency to pitch up after ground spoiler deployment and the captain's reference to it during interviews prompted the Safety Board to evaluate the role of the pitch-up tendency in the accident sequence. The captain told Board investigators that he was expecting the nose-up pitching moment associated with initial spoiler deployment at MLG spin-up. He stated that he remembered compensating with forward control column input and that he thought the spoilers had deployed at touchdown. Although a portion of the captain's nose-down elevator input at the time of the first touchdown may have been in response to the pitch-up tendency, the input greatly exceeded that required to control this tendency. Therefore, the Safety Board concludes that the MD-11's tendency to pitch up at ground spoiler deployment did not contribute to the accident. Nevertheless, a reduction or elimination of the pitch-up tendency

[23] Instead of the miscalculated 780-foot margin result that influenced the captain's decision to set maximum autobrakes, there was actually a 1,680-foot margin.

would simplify MD-11 landing techniques and may help prevent future MD-11 landing incidents and accidents.

MD-11 Pitch Handling Characteristics and the Flight Control Computer (FCC)-908 Software Upgrade

The FCC-908 software package[24] developed by Boeing will alter the handling of the airplane during landings by decreasing the pitch sensitivity through action of the pitch rate damper. The decrease in pitch sensitivity combined with additional handling improvements included in the FCC-908 upgrade should render the airplane less susceptible to overcontrol in pitch similar to that involved in this accident. Boeing's stated goal in implementing FCC-908 is to match the handling characteristics of the MD-11 to those of the existing DC-10 and the DC-10's newly developed two-pilot adaptation, the MD-10, thereby facilitating FAA approval of a common type rating for the MD-10 and MD-11. The DC-10 and MD-10 do not have the pitch sensitivity that, until implementation of the FCC-908 software upgrade, has been characteristic of the MD-11.

Further, the MD-11 FCC-908 software upgrade may help prevent tailstrikes by providing pitch attitude protection and eliminating the MD-11's nose-up pitching tendency at touchdown through the positive nose-lowering feature of FCC-908. The Safety Board concludes that the handling changes incorporated in the MD-11 FCC-908 software upgrade will provide valuable improvements in safety during MD-11 landings. Therefore, the Safety Board believes that the FAA should require the installation, within 1 year, of the MD-11 FCC-908 software upgrade on all MD-11 airplanes.

The Safety Board notes that for an MD-11 equipped with the FCC-908 software package, the longitudinal stability augmentation system (LSAS) will apply elevator control inputs simultaneous with those of the pilots. The Safety Board concludes that with the information that is currently available from the FDR, it may be impossible to distinguish the control inputs of the MD-11 FCC-908 LSAS from the pilots' control inputs. As a result of discussions with Board staff on this subject, Boeing advised the Board that it plans to issue a service bulletin and digital flight data acquisition unit upgrade kit to add some LSAS-associated parameters to the digital flight data recorder (DFDR) data stream.

The Safety Board notes that a requirement for additional FDR parameters is supported by 14 CFR 25.1459(e), which states, "Any novel or unique design or operational characteristic of the aircraft shall be evaluated to determine if any dedicated parameters must be recorded on flight recorders in addition to or in place of existing requirements." Therefore, the Safety Board believes that the FAA should require, on all MD-11s equipped with the FCC-908 software, the retrofit of DFDR systems with all additional parameters required to precisely identify and differentiate between pilot and LSAS elevator control activity, including control column force,

[24] Boeing's FCC-908 software upgrade was FAA-certified on May 23, 2000. The upgrade primarily comprises modifications to three subfunctions—pitch rate damper, pitch attitude protection, and positive nose lowering—of the longitudinal stability augmentation system.

inertial reference unit pitch rate, LSAS command signals, elevator positions, and automatic ground spoiler (AGS) command signals.

MD-11 Ground Spoiler Knockdown Feature

The Safety Board also evaluated the role of the MD-11 ground spoiler knockdown feature in the accident sequence. MD-11 and DC-10 ground spoilers will not deploy if the No. 2 TRA is greater than 44° to 49°, or just above flight idle. This logic is intended to prevent spoiler deployment or retract spoilers during go-arounds. Go-arounds are characterized by large thrust increases near or above takeoff thrust. The Board is concerned that the MD-11's TRA threshold may be too low to allow for power applications to accommodate moderate sink rate and airspeed control techniques near the ground without disarming the AGS system.

Examination of the accident data shows that TRAs rapidly increased from near idle to about 75° (near takeoff thrust) just before touchdown, which prevented ground spoiler deployment at touchdown and contributed to the bounce. The Safety Board does not consider this large and rapid TRA increase to be consistent with a moderate attempt to control sink rate or airspeed and believes that even a modified DC-10 or MD-11 knockdown feature would likely have prevented spoiler deployment given such a large TRA increase. Further, DC-10 and MD-11 training and procedures require pilots to manually deploy ground spoilers if they do not automatically deploy. Therefore, the Safety Board concludes that the MD-11's TRA-driven spoiler knockdown feature did not contribute to this accident.

Nevertheless, the Safety Board notes that it is possible to modify the existing DC-10 and MD-11 spoiler deployment system to allow greater throttle movement before the spoiler knockdown feature is activated. Delaying the knockdown feature would allow pilots to make larger thrust increases just before landing without preventing ground spoiler deployment at touchdown, which may help prevent or minimize some bounces. In the event of a go-around, the higher knockdown angle would slightly delay the retraction of ground spoilers; therefore, a study to determine an optimum angle for activation of the knockdown feature would be necessary. Therefore, the Safety Board believes that the FAA should review and, if appropriate, revise the DC-10 and MD-11 TRA-driven ground spoiler knockdown feature to ensure that it does not prevent ground spoiler deployment at moderate TRAs that could be associated with sink rate and airspeed corrections during the landing phase. Further, the Safety Board believes that the FAA should require DC-10 and MD-11 operators to provide their pilots with information and training regarding the ground spoiler knockdown feature and its effects on landing characteristics and performance.

Transport-Category Airplane Stability and Control During the Landing Phase

The records of previous MD-11 accidents and incidents, including the accident airplane's two hard landing events that preceded the Newark accident,[25] have drawn attention specifically to

[25] FedEx maintenance documents indicated that on January 4, 1994, the accident airplane sustained damage during a bounced landing at Memphis, Tennessee, when a 2.85 positive g load and a minus .45 lateral g load were applied to the airframe during the second touchdown. The airplane also sustained damage from a tailstrike during

the landing characteristics of the MD-11. However, other transport airplane types, including the Boeing DC-10 and 757/767 (as cited by the Safety Board in its June 16, 1994, safety recommendation letter), also have been involved in landing accidents that were or could have been catastrophic. Although improved pilot training in landing techniques and installation of the FCC-908 software upgrade can help prevent MD-11 landing incidents and accidents, the accident history involving the MD-11 and other transport airplane types prompted the Board to consider and review existing certification criteria for airplane handling qualities during landing operations.

The review indicated that, besides basic stability criteria, few objective standards exist for the assessment and acceptance of these handling qualities, including the interactions of airplane and pilot responses and the effects of adverse environmental conditions. Based on the accident and incident record, the Safety Board is concerned that certain complex system interactions, pilot input characteristics, and other factors, such as c.g. position and atmospheric conditions, may occasionally combine during the landing phase in undesirable ways that were not identified during the original certification of transport airplanes. Thus, the Safety Board concludes that additional basic research to identify undesirable landing phase combinations and to compare the overall qualitative and quantitative stability and control characteristics of widely used, large transport-category airplanes is needed to improve certification criteria and reduce the incidence of potentially catastrophic landing accidents.

Therefore, the Safety Board believes that the FAA should sponsor a National Aeronautics and Space Administration (NASA) study of the stability and control characteristics of widely used, large transport-category airplanes to

(a) Identify undesirable characteristics that may develop during the landing phase in the presence of adverse combinations of pilot control inputs, airplane c.g. position, atmospheric conditions, and other factors; and

(b) Compare overall qualitative and quantitative stability and control characteristics on an objective basis. The study should include analyses of DC-10 and MD-11 landing accidents and any other landing incidents and accidents deemed pertinent by NASA.

Further, the Safety Board believes that, based on the results of the study, the FAA should implement improved certification criteria for transport-category airplane designs that will reduce the incidence of landing accidents.

Right-Wing Structural Design and Failure

Title 14 CFR Part 25 requires that an airplane's landing gear and associated structure be able to withstand a 12 fps vertical speed when landing at maximum landing weight on one gear at zero roll angle and 1.0 g lift. This equates to a maximum energy capacity for a single MD-11 MLG, as required for certification, of 494,500 ft-lbs. Boeing estimates that the MD-11 landing gear strut will bottom and cause the wing rear spar to fail if approximately more than

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a bounced landing at Anchorage, Alaska, on November 4, 1994, when a 2.59 positive g load was applied to the airframe during the second touchdown.

1,500,000 ft-lbs of energy is transmitted into a single MLG. At 13.5 fps vertical speed, 0.5 g vertical acceleration, and 8° roll angle, the accident airplane's right MLG experienced an energy input of 1,574,000 ft-lbs during the second touchdown, which was 3.2 times the maximum certification energy and slightly greater than the MD-11's estimated ultimate capability.

Mechanical Dynamics, Inc. (MDI)/Boeing structural simulations[26] of the accident sequence indicate that the right MLG strut and outboard tires bottomed at the second touchdown. Energy not absorbed by the landing gear was then transmitted to the right wing rear spar through the right MLG attach points. A corresponding down load was introduced from the left wing and fuselage, which produced additional torsional loads on the right wing. These torsional loads then produced a shear overload condition in the right wing rear spar according to MDI/Boeing simulations. Boeing stated that the MDI simulations indicate that the failure most probably "initiated at the rear spar/bulkhead (trunnion) rib interface and progressed through the primary wing box structure. As a result of this failure, the right MLG trunnion moved substantially upward and aft with respect to the trap [trapezoidal] panel fitting." Thus, the Safety Board concludes that the energy transmitted into the right MLG during the second touchdown was 3.2 times greater than the MD-11's maximum certificated landing energy and was sufficient to fully compress (bottom) the right MLG strut and cause structural failure of the right wing rear spar.

Runway sooting consistent with a fuel fire near the right MLG was also found at the area of the second touchdown. Thus, on the basis of runway evidence, analysis of performance data, and the MDI/Boeing structural simulations, the Safety Board concludes that the structural failure of the right wing rear spar resulted in the rupture of the right wing fuel tanks and fire.

Landing Gear Certification

The MD-11 MLG was designed to break from the wing (fuse) in a drag overload condition but not in a vertical overload condition. Boeing has stated that this design was implemented because data indicated that the most likely landing gear overload condition would occur as a result of striking an obstruction. This "sacrificial shedding" of MLG assemblies in the aft direction was intended to prevent catastrophic loads being transmitted to the wing box and causing rupture.

During its investigation of the FedEx Newark accident, the Safety Board reviewed the circumstances of several accidents involving other wide-bodied airplane types that greatly exceeded aircraft structural limits. On December 21, 1992, a Martinair DC-10 touched down at Faro, Portugal,[27] with a sink rate of 17 fps, at vertical energy loads 2.6 times greater than energy

[26] Boeing contracted with MDI, a Michigan-based company specializing in dynamic simulation, for assistance in developing a computer model of the airplane structure to simulate its flightpath based on the FDR data and determine the resulting dynamic loading imparted to the aircraft structure during the accident. The Safety Board's Airplane Performance Group reviewed this simulation effort and verified the methodology.

[27] Director-General of Civil Aviation. 1992. *McDonnell Douglas Corporation DC-10-30F, Martinair Holland NV, Final Report on the Accident Occurring at Faro Airport—Portugal, on 21 December 1992,* Report no. 22/Accid/GD1/92. The report was translated from Portuguese into English by the Netherlands Aviation Safety Board.

certification requirements for a single MLG. On July 30, 1992, a TWA L-1011 landed in New York[28] at 14 fps, exhibiting vertical energy loads more than twice its certification requirements.

Current landing phase structural design requirements only require consideration of 1.0 g vertical acceleration, small roll angles, and sink rates up to 12 fps. Manufacturers are also required to consider landing gear overloads in the up and aft directions but have the option of either fusing or overdesigning the gear for such loads. Several major landing accidents have now occurred as a result of pilots allowing their airplanes to land with more adverse combinations of lift, roll angle, and sink rate than those specified in the regulations. In each accident, a wing broke and a fuel fire erupted. Each of these accidents involved aircraft whose landing gear were not fused for upward (vertical) acting loads, which concerns the Safety Board. The Safety Board concludes that the failure modes and effects for vertically fused and overdesigned landing gear designs may have been inadequately researched to identify whether, under overload conditions, one design might provide a safer break-up sequence for the airplane than the other design. Therefore, the Safety Board believes that the FAA should conduct a study to determine if landing gear vertical overload fusing offers a higher level of safety than when the gear is overdesigned. If fusing offers a higher level of safety, the FAA should revise 14 CFR Part 25 to require vertical overload fusing of landing gear.

Further, peak vertical acceleration values recorded by the FDR at landing may not be sufficient for maintenance personnel to determine whether structural damage may have occurred during the landing. Data from the Newark accident indicate that initial vertical acceleration, pitch and roll rates, and attitudes should also be considered during FDR readout and evaluation of a potential hard landing event. The Safety Board notes that Boeing has revised its MD-11 maintenance manual to incorporate this guidance and that the company plans to revise the maintenance manuals of its other products based on the revised MD-11 maintenance manual example. However, the Board is concerned that this guidance will not be available to operators of non-Boeing products and that it is not binding.

Thus, the Safety Board concludes that current manufacturer guidance for hard landing identification and operator maintenance readouts and analysis of FDR data following suspected hard landings may not be adequate to identify landings in which structural damage may have occurred. Therefore, the Safety Board believes that the FAA should require manufacturers of 14 CFR Part 23 and Part 25 airplanes and Part 121 operators to revise their hard landing inspection and reporting criteria to account for all factors that can contribute to structural damage. The FAA should also instruct principal maintenance and operations inspectors assigned to Part 121 operators to ensure that these changes have been made to operator maintenance manuals and Flight Operations Quality Assurance exceedence monitoring programs.

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[28] National Transportation Safety Board. 1993. *Aborted Takeoff Shortly After Liftoff, Trans World Airlines Flight 843, Lockheed L-1011, N11002, John F. Kennedy International Airport, Jamaica, New York, July 30, 1992*. Aircraft Accident Report NTSB/AAR-93/04. Washington, D.C.

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

> Convene a joint government-industry task force composed, at a minimum, of representatives of manufacturers, operators, pilot labor organizations, and the Federal Aviation Administration to develop, within 1 year, a pilot training tool to do the following:
>
>> Include information about factors that can contribute to structural failures involving the landing gear, wings, and fuselage, such as design sink rate limits; roll angle limits; control inputs' roll rate; pitch rate; single-gear landings; the effect of decreased lift; and structural loading consequences of bottoming landing gear struts and tires; (A-00-92)
>>
>> Provide a syllabus for simulator training on the execution of stabilized approaches to the landing flare, the identification of unstabilized landing flares, and recovery from these situations, including proper high sink rate recovery techniques during flare to landing, techniques for avoiding and recovering from overcontrol in pitch before touchdown, and techniques for avoiding overcontrol and premature derotation during a bounced landing; (A-00-93) and
>>
>> Promote an orientation toward a proactive go-around. (A-00-94)
>
> Require principal operations inspectors assigned to Part 121 carriers that use auxiliary performance computers to review and ensure the adequacy of training and procedures regarding the use of this equipment and the interpretation of the data generated, including landing distance data. (A-00-95)
>
> Require the installation, within 1 year, of the MD-11 flight control computer-908 software upgrade on all MD-11 airplanes. (A-00-96)
>
> Require, on all MD-11s equipped with the flight control computer-908 software, the retrofit of digital flight data recorder systems with all additional parameters required to precisely identify and differentiate between pilot and longitudinal stability augmentation system (LSAS) elevator control activity, including control column force, inertial reference unit pitch rate, LSAS command signals, elevator positions, and automatic ground spoiler command signals. (A-00-97)
>
> Review and, if appropriate, revise the DC-10 and MD-11 throttle resolver angle (TRA)-driven ground spoiler knockdown feature to ensure that it does not prevent ground spoiler deployment at moderate TRAs that could be associated with sink rate and airspeed corrections during the landing phase. (A-00-98)
>
> Require DC-10 and MD-11 operators to provide their pilots with information and training regarding the ground spoiler knockdown feature and its effects on landing characteristics and performance. (A-00-99)

Sponsor a National Aeronautics and Space Administration (NASA) study of the stability and control characteristics of widely used, large transport-category airplanes to

Identify undesirable characteristics that may develop during the landing phase in the presence of adverse combinations of pilot control inputs, airplane center of gravity position, atmospheric conditions, and other factors; and

Compare overall qualitative and quantitative stability and control characteristics on an objective basis.

The study should include analyses of DC-10 and MD-11 landing accidents and any other landing incidents and accidents deemed pertinent by NASA. (A-00-100)

Based on the results of the study recommended in Safety Recommendation A-00-100, implement improved certification criteria for transport-category airplane designs that will reduce the incidence of landing accidents. (A-00-101)

Conduct a study to determine if landing gear vertical overload fusing offers a higher level of safety than when the gear is overdesigned. If fusing offers a higher level of safety, revise 14 Code of Federal Regulations Part 25 to require vertical overload fusing of landing gear. (A-00-102)

Require manufacturers of 14 Code of Federal Regulations Part 23 and Part 25 airplanes and Part 121 operators to revise their hard landing inspection and reporting criteria to account for all factors that can contribute to structural damage; instruct principal maintenance and operations inspectors assigned to Part 121 operators to ensure that these changes have been made to operator maintenance manuals and Flight Operations Quality Assurance exceedence monitoring programs. (A-00-103)

Chairman HALL and Members HAMMERSCHMIDT, GOGLIA, BLACK, and CARMODY concurred in these safety recommendations.

Original Signed

By: Jim Hall
Chairman