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Inadvertent Inflight Slat Deployment on MD-11 Results in Two Fatalities, 156 Injuries

Inadequate flap/slat handle design, lack of pilot training in recovery from high-altitude upsets and lack of seat-belt usage cited in U.S. official report.

by
Russell Lawton
Aviation Consultant

An inadvertent slat deployment on a China Eastern Airlines McDonnell Douglas MD-11 while in cruise flight has resulted in a U.S. Federal Aviation Administration (FAA) airworthiness directive (AD) to prevent future occurrences, and in an expedited review to redesign the flap/slat actuation system on the MD-11. Of the 235 occupants, two passengers died, and 149 other passengers and seven crew members received various injuries after several violent pitch oscillations resulting from the slat deployment.

China Eastern Airlines Flight 583 (CES 583) was a scheduled international passenger flight from Shanghai, China, to Los Angeles, California, on April 6, 1993. While cruising at Flight Level 330 (33,000 feet [10,065 meters]) and approximately 950 nautical miles (1,758 kilometers) south of Shemya, Alaska, the leading edge wing slats deployed. The autopilot disconnected, and the captain was manually controlling the airplane when it progressed through several violent pitch oscillations and descended 5,000 feet (1,525 meters). The captain regained stabilized flight, declared an emergency because of passenger injuries and diverted to a U.S. Air Force base in Shemya. The airplane received no external structural damage, but the passenger cabin was damaged extensively.

According to the U.S. National Transportation Safety Board (NTSB) accident report, the accident resulted from "the inadequate design of the flap/slat actuation handle by the Douglas Aircraft Company [DAC] that allowed the handle to be easily and inadvertently dislodged from the UP/RET position, thereby causing extension of the leading edge slats during cruise flight. The captain's attempt to recover from the slat extension, given the reduced longitudinal stability and the associated light control-force characteristics of the MD-11 in cruise flight, led to several violent pitch oscillations."

The report stated, "Contributing to the violence of the pitch oscillations was the lack of specific MD-11 pilot training in recovery from high-altitude upsets, and the influence of the stall warning system on the captain's control responses. Contributing to the severity of the injuries was the lack of seat restraint usage by the occupants."

The report said that the airplane's cockpit voice recorder (CVR) provided no useful information for the investigation because the continuous-loop tape had not been erased prior to the recording of new audio information. In addition, the digital flight data acquisition unit (DFDAU) failed several hours prior to the extension of the slats; thus, the flight data recorder (FDR) did not record slat command and position information, the report said.

CES 583 departed Beijing, China, for Los Angeles with an intermediate stop in Shanghai. The report said that the flight crew reported that the operation of the airplane from Beijing to Shanghai was normal. The crew also reported that the takeoff, climb and initial en route segment of the flight from Shanghai to Los Angeles were normal, the report said.

The NTSB report said, "The airplane had been airborne about five hours, and the flight attendants had completed the meal service and had dimmed the lights for a movie when the airplane began the violent pitch oscillations."

The captain told NTSB investigators that he was "one of four members of the oncoming relief flight crew that had assumed flight responsibilities of the airplane approximately 20 minutes prior to the accident. The captain further stated that he was the pilot flying but occupied the right seat at the time of the accident because he was providing instruction to the first officer in the left seat.

"At the time of the accident, the airplane was in cruise flight at Flight Level 330, above the clouds and at an indicated airspeed of approximately 298 knots (Mach 0.82) with the No. 1 autopilot engaged. The captain stated that the crew had not experienced any 'unusual weather phenomenon' until approximately 15 minutes prior to the event. At that time, the airplane encountered what he described as 'light' turbulence, and he turned on the seat belt sign. He also stated that shortly thereafter, the 'turbulence increased.'"

The report said that the captain believed that the cockpit instrument indications, warnings and extension of the slats resulted from turbulence. The FDR data and interviews with passengers and flight attendants indicated that the flight had been "smooth" and the "fasten seat belt" sign was not illuminated prior to the upset. The report stated, "Based on evidence gathered from passenger statements, weather analysis, pilot reports (pireps) from other aircraft on similar routes of flight shortly before and after the accident, as well as FDR information, the Safety Board concluded that no turbulence existed in the immediate area before and during the accident sequence. It is most probable that the vibrations, caused by the initiation of the slat extension above the maximum design speed, were perceived as turbulence by the flight crew.

"The captain also stated that prior to the accident he observed a second Mach speed indication (depicted by an open circle with the speed 0.728) below the selected flight management computer (FMC) command speed indication (depicted by a solid circle with the speed 0.82) on the right side primary flight display (PFD) airspeed indicator," the report said. He said that the second Mach indication was 'usually not displayed,' and that he had attempted to correct the secondary indication by momentarily engaging the autopilot speed command and then disengaging the system. This action was unsuccessful, so he attempted to correct the airspeed indication with inputs to the FMC through the No. 2 multifunction control display unit (MCDU), the report said. This action was also unsuccessful, and the secondary Mach indication remained visible on the airspeed indicator.

"At the time of the accident, the airplane was in cruise flight at Flight Level 330, above the clouds, and at an indicated airspeed of approximately 298 knots (Mach 0.82) with the No. 1 autopilot engaged."

The report said, "The captain also stated that when they experienced the 'increase in turbulence,' he observed the white SLAT light with a down arrow illuminate on the PFD. In addition, he stated that the angle-of-attack (AOA) bars had changed color on the PFD from cyan to red (indicating a stall condition), the stall warning stick shaker activated and, at the same time, the 'slat overspeed' warning chime sounded. The captain stated that he immediately verified that the flap/slat handle was in the retracted position by pushing the handle forward, and the flight engineer placed his hand on the flap/slat handle twice to ensure that the handle remained forward in the retracted position.

"According to the FDR information, the airplane was in a slow right turn (initiated by a change in selected heading) at 296 knots indicated airspeed (KIAS) with the No. 1 autopilot engaged when a slat disagree indication was recorded. Slat position, pressure altitude, roll angle and other data were not recorded by the FDR because of a prior failure within the airplane's DFDAU; therefore, values of those parameters during the accident flight are not known.

"The outboard ailerons began to move at this point. About seven seconds after the slat disagree indication was recorded, the airplane began pitching nose up despite autopilot-commanded nose-down elevator deflections (the autopilot elevator deflections were not sufficient to counteract the nose-up pitch movement induced by deployment of the slats). Three seconds later, the stall warning system activated while pitching nose up through 7.4 degrees at 296 KIAS and +1.37 g. One second later, the airplane reached a maximum nose-up pitch attitude of 9.5 degrees, the airspeed decreased to 293 KIAS and the vertical acceleration peaked at +1.50 g. The airplane then began to pitch nose down.

"After a nose-down pitch rate was established, the elevators began moving in the nose-up direction. Approximately two seconds later (about 13 seconds after the slat disagree indication), as the nose-down pitch rate was decreasing and vertical acceleration began to increase, the FDR recorded a rapid movement of the elevators in the nose-down and then nose-up directions, followed immediately by deactivation of the stall warning system and disengagement of the No. 1 autopilot. The airplane reached 5.6 degrees nose-down pitch at 286 KIAS and -0.29 g, and then it started to pitch nose up.

"The airplane completed a second (during which another stall warning occurred), a third (during which the slat disagree indication deactivated) and a fourth pitch oscillation during the next 13 seconds. The maximum and minimum pitch attitudes became increasingly nose down during the oscillations, reaching a maximum of 24.3 degrees nose down at the bottom of the fourth oscillation. Vertical acceleration oscillated divergently (increasing amplitude) during the second and third pitch oscillations, reaching peak values of +1.53 g and -1.24 g during the third, and then began to converge during the fourth oscillation as airspeed increased through 320 KIAS."

After the fourth pitch oscillation was completed, "nose-up elevator deflection and vertical acceleration began to increase rapidly," the report said. "The FDR data became unrecoverable at this point for undetermined reasons. The FDR data once again became recoverable approximately five seconds later with the airplane pitching through 15 degrees nose down, vertical acceleration decreasing through +2.0 g and airspeed still increasing through 337 KIAS.

"The airplane then began to recover out of its oscillating descent (reported by the crew to have ended at approximately 28,000 feet [8,540 meters]) with pitch attitude steadily increasing and the pitch and vertical acceleration oscillations damping considerably as a result of smaller (although still oscillating) elevator deflections. An overspeed warning was recorded by the FDR as the airplane was pulling out with airspeed increasing through 348 KIAS. Airspeed peaked at 364 KIAS before beginning to decrease, and the overspeed warning deactivated as the airspeed decreased through 360 KIAS.

"Pitch attitude stopped increasing at approximately seven degrees nose up and oscillated between five and eight degrees nose up as the aircraft climbed. The No. 2 autopilot was engaged approximately 30 seconds later (94 seconds after the initial slat disagree indication), after which the elevator position, pitch attitude and vertical acceleration oscillations stopped. The airplane continued its climb and then leveled (at Flight Level 330, according to the crew). The FDR indicates that the airplane maintained stabilized flight during the remainder of the flight to Shemya.

"Prior to the accident, the radio operator was providing position reports to the Honolulu Aeronautical Radio Inc. (ARINC) communication specialist, who, in turn, transmitted the airplane's position to the Oakland Air Route Traffic Control Center (ARTCC).

"At 0123 Hawaiian Standard Time (HST), the Honolulu ARINC communication specialist received a request from Flight 583 for a deviation to the nearest airport because of an emergency. One minute later, [CES 583] reported that the emergency was due to a 'sick passenger.' At 0125, the radio operator on [CES 583] again contacted the Honolulu ARINC and reported that there were injured passengers on board because of 'severe turbulence,' and he declared an emergency. Through ARINC, the Oakland ARTCC controller then issued a clearance for Flight 583 to divert to Shemya.

"The airplane remained airborne for approximately two hours after the accident, and the flight crew dumped fuel en route to reduce the airplane's landing weight. At 0329, an uneventful landing after an instrument landing system (ILS) approach was made at Shemya.

"The U.S. Air Force, [U.S.] Coast Guard and [U.S.] Navy provided several airplanes to evacuate injured persons to four hospital facilities in Anchorage," the report said. "One male passenger succumbed to fatal injuries before the airplane landed at Shemya, and a second male passenger died in an Anchorage hospital one week after the accident. Both passengers had sustained severe head injuries. A total of 149 passengers received injuries, ranging from minor abrasions and contusions to spinal fractures, rib fractures and life-threatening head injuries, including one passenger who was paralyzed. The most serious injuries occurred to unrestrained passengers who were located in the aft cabin.

The most serious injuries occurred to unrestrained passengers who were located in the aft cabin.

"Three flight crew members and four flight attendants also received serious injuries, including one flight attendant who sustained severe brain damage."

The report said that the circumstances that precipitated the pitch oscillations were such that a warning to the flight attendants and passengers was not possible and that those persons who were unrestrained in the mid and aft cabins received the majority of the serious injuries, the report said.

"According to some flight attendants and passengers, the 'fasten seat belt' sign was not on prior to the onset of the pitch oscillations, but it did illuminate during the second oscillation," the report said.

Shortly after the pitch oscillations began, the flight attendant "who was assigned to the forward left cabin door rushed forward to catch the microphone, but she was heavily pressed against the floor," the report said. "At the same time, two flight attendants in the front cabin and a flight attendant in the rear cabin instinctively shouted, 'Turbulence fasten seat belt.' The flight attendant then announced on the public address system, 'Turbulence occurred due to unsteady airflow, please fasten your seat belts and do not use washrooms,'" the report said.

"Passengers reported that it was difficult to hear the public address announcements during the normal portion of the flight and that following the upset, it was 'impossible' to hear the announcements," the report said. "During the postaccident examination of the cabin, two portable megaphones that were operational were found stowed in the overhead bins."

"Passengers described the pitch oscillations as a series of two or three cycles in which unrestrained passengers were alternately lifted to the ceiling and dropped to the floor, or aisle or into seats other than those they had originally occupied," the report said. "Passengers also reported striking the ceiling, armrests, seats and/or other passengers during the oscillations."

Several overhead storage bins in the mid and aft cabins opened during the upset.

Several overhead storage bins in the mid and aft cabins opened during the upset. Passengers said that luggage fell from overhead storage bins striking several people in the mid and aft cabins during the upset. Another passenger stated "that one of the overhead bins that opened had been 'stuffed' before departure and that the flight attendant 'had to pound on the bin's door with her fist' to close and secure the bin," the report said.

"Two passengers reported that flight attendants provided them with oxygen following the upset," the report said. "A third passenger, who also received oxygen, stated that the two oxygen bottles given to him by a flight attendant did not operate properly and that a third oxygen bottle was empty. Another passenger expressed concern that several passengers were smoking while oxygen was being administered. Several passengers reported that a Chinese physician assisted injured persons following the upset."

The airplane was configured for a four-person flight crew in the cockpit and 14 flight attendant seats throughout the passenger cabin. There was no damage to any of the flight-crew seats or flight-attendant seats or seat-restraint systems.

The passenger cabin was configured for 46 business-class seats and 294 coach-class seats. "The primary damage occurred to the interior structure and seats in the coach-class section," the report said. "The damage to the passenger seats ranged from slight deformation to distortion and/or complete collapse of the seat armrests and seat backs."

Several passenger service units (PSUs) in the coach-class section sustained impact damage when they were struck by passengers, the report said. "The damaged PSUs had been displaced or pushed up into their mounting structure. Twenty oxygen masks, in various parts of this cabin section, were found deployed as a result of damage to the PSUs."

The report added: "Numerous ceiling panels in the forward coach cabin and all of the ceiling panels in the aft cabin of the coach section were damaged, and some were displaced upward against their support frames. About 80 percent of the ceiling cross beams, which support the ceiling panels in the aft section of the airplane, were found crimped, separated or bent."

An examination of the accident airplane's structure was conducted at Shemya prior to a ferry flight to Los Angeles International Airport to remove cargo and baggage. No external damage was found, and the airplane was released for flight. The airplane was then ferried to the DAC facility at Long Beach, California, for further examination, testing and repairs; repair cost was US$1.5 million.

The MD-11 was certificated by the FAA in 1990 and began commercial service in 1991. There are currently 100 airplanes in service worldwide with 15 operators, the report said. The accident airplane is one of five MD-11s that were delivered to China Eastern Airlines. The airplane's maximum gross weight is 625,500 pounds (283,727 kilograms), and the maximum gross takeoff weight for CES 583 was 618,000 pounds (280,325 kilograms). The MD-11 is capable of carrying between 250 and 410 passengers (depending on seat configuration) and has a range of approximately 7,960 statute miles (12,807.6 kilometers). CES 583 was configured with 298 passenger seats, the report said.

The standard MD-11 flight deck is configured for a two-pilot flight crew and two jumpseats. China Eastern Airlines operates the MD-11 with a four-person flight crew, consisting of a captain, first officer, flight engineer (second officer) and radio operator (third officer).

"As of April 6, 1993, the accident airplane had accumulated approximately 4,810 total flight hours and 1,571 flight cycles. A review of the records indicated that the airplane had not been involved in any previous incidents or accidents," the report said. The flap/slat handle on the accident airplane had been "modified in accordance with all applicable manufacturer's service bulletins (SBs) and FAA airworthiness directives (ADs)," the report said.

The MD-11 is equipped with six cathode-ray tube displays, dual flight management systems and an automatic flight control system (autopilot) with fail-operational capability. The airplane has eight leading edge slat segments on each wing. Two of the eight segments are inboard of each wing-mounted engine. The slats are activated “by a series of cables, hydraulic valves and mechanical linkages that are operated by an integrated flap/slat control handle” in the cockpit.

“As a requirement to meet FAA certification, the slat input system incorporates an extend bias, which is a combination of slat cable tension and a preloaded spring force, that pulls the flap/slat handle aft toward the slat extend position. The bias was necessary to provide a means of retaining the slats in the extended position in the event of a catastrophic failure in the slat control system. Due to this bias, the handle will move aft if it not securely held in the selected detent position on the flap/slat handle module,” the report said.

During the investigation, the flap/slat handle on the accident airplane “was found to operate normally through its range of movement,” the report said. Examination of the slat stow lever revealed that when the lever was pushed forward (the disconnect position) and then released, the lever did not return to its normal position, the report said. The lever was operationally tested several times, and it was determined that it could not be manipulated in such a manner that would cause or permit an uncommanded slat extension. “The flap/slat handle module was examined and found to be within design limits, with the exception of the slat stow lever,” the report said.

“The MD-11 also has an autoslat system that will extend the outboard slats automatically if the wing is at a stall angle of attack and all of the following conditions exist: the airspeed decreases below 280 knots or Mach 0.55, the flaps are less than three degrees and the slats are not extended,” the report said. “When the stall condition ceases, the autoslat system retracts the slats. The inboard slats remain stowed during the autoslat extension and will not extend unless commanded by movement of the flap/slat handle. An autoslat extension does not cause the outboard ailerons to unlock.

“The position of the slats is detected by proximity sensors located in the left and right wings. Slat position is shown on both the primary flight display (PFD) and the system display electronic pages.

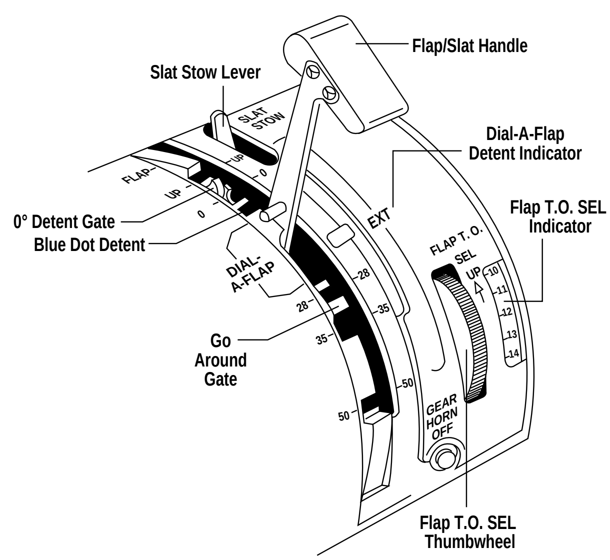
“The PFD provides the flightcrew with a variety of information, including flap-handle position and flight-mode annunciations. Flap and slat indications are shown on the PFD, adjacent to and below the airspeed tape.

“A white arrow indicates the direction of slat movement (arrow down = extend, arrow up = retract). The SLAT indication illuminates amber momentarily during extension, when the slats do not extend symmetrically or when they require more than 13 seconds to extend. During retraction, the SLAT indication illuminates amber when the slats do not retract symmetrically or when they require more than 30 seconds to retract.

The report said, “During the postaccident interview, the captain stated that he observed a white SLAT indication with a down arrow on the PFD and, shortly thereafter, heard the aural slat overspeed warning. He also stated that neither the master caution warning nor the Engine and Alerts Display (EAD) illuminated.”

The report added: “Operation of the flaps and slats is accomplished by a single handle located on the right side of the cockpit center pedestal (Figure 1). To extend only the slats, the flap/slat handle is moved from the UP/RET detent to the 0/EXT detent. Further aft movement of the flap/slat handle will command the extension of the flaps, up to a maximum of 50 degrees.

Flap/Slat Handle Module



Source: McDonnell Douglas Corporation/U.S. National Transportation Safety Board

Figure 1

“To extend the flaps without extending the slats, the flap/slat handle must be positioned in the UP/RET detent. From this position, the handle is then lifted up and moved aft while holding the slat stow lever fully forward. This procedure will disconnect the slat input from the flap/slat handle and leave the slats in the retracted position. Once the flap handle is returned to the UP/RET detent, the slat input will automatically reconnect to the flap/slat handle.

“The primary reason for the slat stow lever is to allow operation of the flaps when the slat input system is malfunctioning or [has] failed. With the slats in the retracted or stowed position, the flap handle can be moved without slat input to the system."

The report said that the centralized fault display unit (CFDS) is a "fault display system that is connected to the airplane's subsystems and stores detected faults about such monitored systems as flight controls, navigation and communications. The fault information is continuously recorded and identified by flight number and the clock time. The fault information is retrievable through any one of the three displays in the cockpit.

"A review of the aircraft fault data recorded by the CFDS revealed that several system malfunctions or faults had occurred approximately 13 minutes prior to the pitch oscillations. … It was determined that these faults would have required a flight crew member to perform manual inputs through a keypad to restore the navigation data on the No. 2 (right side) navigation display, the report said. The keypad is located on the right side of the center pedestal, forward and below the flap/slat handle."

"Examination of the CVR revealed an anomalous 'run-on' of the unit after the accident, consistent with the continuous-loop tape not being erased prior to recording new audio information."

The accident airplane was equipped with a Fairchild CVR model A100A that records cockpit area sounds on a continuous-loop 30-minute magnetic tape. "No information pertinent to the investigation was derived due to a mechanical malfunction," the report said. "Examination of the CVR revealed an anomalous 'run-on' of the unit after the accident, consistent with the continuous-loop tape not being erased prior to recording new audio information. Consequently, the audio tape contained several superimposed recordings, none of which could be associated with the accident."

The CVR was further examined and a functional analysis was conducted by Loral Data Systems, the manufacturer of the unit. The analysis revealed that a capacitor had failed within the unit. The report said that the manufacturer stated, "This is the first time that such a defect has been observed or reported … in over 20,000 CVR units. The fault detection circuit of the A100 was not designed to, nor was it required to, detect such partial failures."

The accident airplane was equipped with a Fairchild FDR model F800 that recorded data in a digital format on a 25-hour continuous magnetic tape and was capable of recording in excess of 250 parameters. The report said that examination of the FDR data "revealed that the pressure altitude, roll angle, total air temperature and slat position (for all slats) data became anomalous approximately 12 hours of FDR time prior to the accident. Subsequent examination of the recorder determined that the DFDAU on the airplane malfunctioned, resulting in anomalous parameter values," the report said.

"The DFDAU was examined to determine why missing parameters and synchronization losses of recorded data occurred during the accident flight," the report said. "The discrepancies were determined to have resulted from a failed programmable read-only memory (PROM) in the DFDAU. Although the DFDAU initially passed a test program during the examination of the unit on the airplane, further examination determined that the unit had malfunctioned. The failure of the DFDAU would not have affected the operation of the inboard slats."

The report said that CES 583 was equipped with a quick access recorder (QAR). "The unit records information on a noncontinuous magnetic tape from various airplane systems that the operator uses for trend monitoring and maintenance of the fleet," the report said. "The QAR system was queried to determine if any information had been recorded during the accident flight; however, no data had been recorded because the tape had run its full length before the accident event."

Thirteen days after the accident, DAC test pilots and flight engineers conducted a flight test with the accident airplane to determine if any anomalies existed in the airplane (especially the leading edge slat system) in flight that would or could not be detected on the ground. "The inflight tests were also intended to evaluate the possible adverse effect that 'cold soaking' of the airplane might have on the slat system," the report said. The airplane was flown at an altitude of 33,000 feet for two hours to approximate the aircraft temperature at the time of the accident, the report said.

The three-hour-and-35-minute flight test was conducted at various altitudes and ambient temperatures. All functional tests were completed with satisfactory results. Slat extension and retraction cycle times were recorded and found to be within DAC production specifications. During the slat extension/retraction cycles, the autopilot remained engaged and properly controlled the pitch axis. No unusual maneuvers or extreme attitude changes occurred.

"In all tests, including the cold-soak tests, when the slats were commanded to retract, the slat valve input crank remained firmly against the retract stop, which is the normal retract position," the report said.

The report said that several attempts were made to dislodge the flap/slat handle from the stowed position by normal crew movements in the cockpit. These movements included striking the handle from the left and right sides by both pilots using normal hand movements and striking forces. It was found that the handle was more susceptible to being dislodged, causing extension of the slats, when the handle was struck on the aft left side by the pilot in the left seat, the report said. However, the handle was dislodged several times intentionally by the right seat pilot by striking the handle on the right rear corner or by snagging the handle knob with a shirt sleeve cuff while moving his hand to program the No. 2 multifunction control display unit (MCDU) or by reaching toward the forward center console area, the report said.

Normal forces applied to the airframe during the flight test had no adverse effect on the slat control system, the report said.

During the investigation, the NTSB reviewed the design stability of the MD-11, and the report said, "The MD-11 is designed to obtain improved aerodynamic efficiency by reducing the aerodynamic download on the horizontal stabilizer during the cruise flight regime, thereby reducing the compensating lift necessary from the wing. Reduction in the lift required translates into a reduction in drag, which, in turn, results in improved, specific fuel consumption.

"The reduction in the aerodynamic download on the horizontal stabilizer is achieved by operating the airplane at an aft center of gravity (CG) maintained by carrying fuel in cells built in the horizontal stabilizer. The lower aerodynamic load requirements permit the stabilizer to be smaller in size, which further reduces aerodynamic drag, thus because of the aft CG and reduced area of the stabilizer, the MD-11 airplane operates in the cruise regime with a smaller stability margin than some other transport category airplanes. DAC refers to this as 'relaxed stability.'

"If the pilot attempts to override the autopilot by direct control-column force, all of the elevators will move, and the pilot will experience significant resistance."

"During the MD-11 design phase, DAC engineers intentionally designed the airplane to be flown with minimum positive or even neutral static longitudinal stability. With low static stability, light control-column forces could produce severe flight loads. Thus, to make the airplane handling characteristics acceptable to pilots, as well as to ensure compliance with the FAA requirements, the airplane is equipped with a longitudinal stability augmentation system (LSAS). This system provides conventional pitch-axis handling characteristics through elevator commands without control-column movement.

"The LSAS is essentially a full-time attitude-hold system that uses the elevators to immediately respond to damp externally induced pitch disturbances. Once the pilot's force on the control column exceeds two pounds, the LSAS system disengages, resulting in unassisted manual control. When force is removed from the control column, the LSAS reengages …"

The report added: "If the pilot attempts to override the autopilot by direct control-column force, all of the elevators will move, and the pilot will experience significant resistance. If the autopilot is disconnected while the pilot is exerting force on the control column to counter the autopilot resistance, an abrupt change in the elevator position will be induced by the pilot before he is able to react to the lessening control-column load. DAC test pilots state that pilots typically react to this abrupt elevator command by overcorrecting in the opposite direction, with larger-than-normal control-column movement that translates into more elevator deflection than would have been commanded by the autopilot."

The NTSB reviewed the qualifications and training of the captain of CES 583. The captain, 42, held a Chinese pilot certificate, equivalent to a U.S. airline transport pilot certificate. He had ratings for the Ilyushin 14, Trident, Airbus A310, A300-600R and the MD-11. At the time of the accident, he had accumulated approximately 8,535 hours of total flight time, of which 1,341 hours were in the MD-11.

The report said that the captain had completed recurrent training approximately one month prior to the accident. "The ground school portion of the training included a review and discussion of information regarding the inadvertent or uncommanded inflight extension of the slats," the report said. "Information from the Douglas interim operating procedures (IOP) was presented and discussed during the captain's recurrent training class. Part of the information included the following:

"If an unintentional deployment of the FLAP/SLAT handle and the slats should occur during cruise, the first cockpit indication that the slats are extending is a momentary amber SLATS annunciation on the captain's and first officer's PFDs, followed by the word SLATS and a downward pointing arrow displayed in white. If this occurs the pilot should act promptly, but smoothly, to prevent entering an unusual attitude, and simultaneously return the FLAP/SLAT handle to the FLAP UP/SLAT RET detent to retract the slats. Return to normal flight conditions will not require abrupt or extreme flight control inputs to safely control the aircraft."

The NTSB's analysis of the accident concentrated on the reasons for the inadvertent extension of the wing leading edge slats and the resulting pitch oscillations, the report said. "This analysis included a review of 10 previous inadvertent slat extensions, the information currently available to operators of the MD-11, interim mechanical devices installed on the flap/slat handle, the design and operation of the flap/slat handle and its interrelated systems, and the pilot's manipulation of the flight controls."

The report said, "A study of the effects of slat deployment found that the extension of only the inboard slats did not cause a pronounced pitch-up tendency, even at airspeeds that were beyond the normal realm of slat operation. However, the extension of the outboard slats results in a loss of lift. Since the loss of lift is behind the center of pressure (due to the sweep of the wing), the airplane tends to pitch nose up.

"Evidence also indicates that even though the attitude change may be very pronounced when the outboard slats extend, the airplane is controllable with minimum pitch control action by the pilot."

"Evidence also indicates that even though the attitude change may be very pronounced when the outboard slats extend, the airplane is controllable with minimum pitch-action control by the pilot. Furthermore, large pitch-control inputs by the pilot may produce severe and unwanted attitude changes of the airplane."

The report said that because the DFDAU had failed several hours prior to the extension of the slats, slat command and actual position information was not available for analysis. "However, the FDR information revealed that the left and right outboard ailerons had unlocked during the accident sequence. This unlocking was significant because the outboard ailerons are normally used when the airplane is operating at slow airspeeds and are locked during cruise flight. The ailerons will only unlock when either the flaps, the slats or the landing gear is extended. The FDR information indicated that the flaps and landing gear were in the UP position and that the airplane was in a nose-up pitch attitude when the ailerons unlocked. Thus, the Safety Board views the unlocking of the ailerons, in combination with the pitch perturbation, as evidence of slat extension," the report said.

Possible mechanical and nonmechanical anomalies that could have affected the operation of the slats were investigated, the report said. "The ground and inflight examination of the slat system components from the accident airplane revealed that the installation of the slat system was correct. In addition, no evidence was found of a mechanical malfunction or a failure of any component or interrelated system that would have resulted in the slats extending without the flap/slat handle being moved out of the UP/RET position. But the investigation did reveal that the flap/slat handle system, even with all the applicable modifications installed, could still be inadvertently dislodged by routine flight crew movements in the cockpit and could cause an undesired extension of the slats," the report said.

The report added, "The Safety Board's analysis of the information derived from interviews with the flight crew and data retrieved from the FDR revealed several possible opportunities for a flight crew member to have inadvertently contacted the flap/slat handle."

The report said that the captain stated that "prior to the encounter with 'turbulence,' he had been attempting to resolve a discrepancy with the FMC Mach number on the airspeed indicator. He said that he momentarily disengaged and then reengaged the autoflight speed command system; however, the discrepancy remained." As a result of this and several other discrepancies, a correction was necessary through inputs to the FMC. "These inputs would have required a crew member to use the MCDU keypad to enter the data and could have resulted in inadvertent contact with the slat handle. The keypad is located on the right side of the center pedestal, slightly forward and below the flap/slat handle."

"The captain, who was in the right seat, would have been the most likely flight crew member to reenter the data because of his close proximity to the No. 2 MCDU keypad," the report said. With the history of inadvertent slat extensions and the all-operator letter (AOL) issued by DAC, "it is most likely that the captain inadvertently contacted the handle while moving his hand in the area of the MCDU keypad. Once the handle was displaced from the UP/RET position, the slat extension cycle began and continued without interruption."

The report said, "At the time the slats began to extend, the attention of the captain, and most likely the first officer, was directed toward the MCDU keypad and the data entry process. The extension of the inboard slats would not have been noticed by the crew initially because it does not significantly affect the airplane's pitch attitude with the autopilot engaged. Also, it is most likely that as the airplane began to pitch upward with the extension of the outboard slats, the autopilot began trying to compensate and apply corrections by deflecting the elevator nose down. However, once the outboard slats extended fully, the flight crew's attention would have been immediately focused on the reason for the airframe buffet, the nose-up pitch rate and the stall warning activation.

"The captain stated that when he felt the buffeting, he saw the white slat indication (slat extended symbol) on the PFD and heard the slat overspeed warning chime. The captain also stated that he took immediate corrective action, which included verifying that the flap/slat handle was securely in the UP/RET position. His second corrective action was to disconnect the autopilot and to manually control the airplane, in an effort to return to the assigned altitude.

The report stated, "It became evident that the primary factor in this accident was the cause of the extreme airplane pitch oscillations that resulted in the injuries to the unrestrained occupants." The report said that the NTSB "examined in detail the pilot control during the upset and resulting oscillations, as revealed by the available FDR data."

Throughout the recovery sequence, "the captain used more control than desirable or needed (approximately 50 percent of full authority) as a result of the airplane's low stick force characteristics, and he delayed elevator control responses until the stall warning deactivated. While the captain responded rapidly to the stall warnings with corrective elevator control, earlier response and lesser control inputs would have been more effective in stabilizing the pitch oscillations. … Each time the stall warning system deactivated, the pilot made nose-up control inputs in an attempt to restore a nose-up pitch attitude," which resulted in an "overshoot," the report said.

"Throughout the recovery sequence, the captain used more control than desirable or needed (approximately 50 percent of full authority) … "

Adding to the overshoot problem was that "the MD-11 stall warning system deactivates one second after the angle of attack (AOA) decreases to the initiation threshold AOA, as a result of a system time delay," the report said. "DAC has indicated that this one-second time delay was intentionally designed into the stall warning system to prevent secondary stall warnings that might otherwise be induced by pilots if the stall warning stops exactly at the point where the stall warning conditions numerically cease. This delay appears to have caused the pilot to maintain nose-down elevator commands … much longer, which tended to push the pitch oscillations … much further into the nose-down regime."

The NTSB cited 12 incidents of inadvertent or uncommanded inflight slat extensions (including CES 583) on the MD-11 since it began commercial service in 1991. CES 583 was the 11th and only event involving occupant injuries and loss of life. Because of the reoccurrence of inadvertent slat extensions, DAC released four service bulletins addressing the flap/slat handle problem, the report said.

"Each service bulletin recommended a modification to the slat system that was intended to reduce the possibility of extending the slats due to the inadvertent aft movement of the flap/slat handle," the report stated. "Although these modifications have decreased the probability of an uncommanded extension, they have not eliminated the potential for further inadvertent slat extensions due to inadvertent contact with the flap/slat handle. Therefore, the Safety Board supports efforts to redesign the MD-11 slat activation system to eliminate all potential for hazardous high speed slat extension."

The NTSB cited five MD-11 incidents "in which inadvertent leading edge slat extension resulted in significant overcontrol-related pilot-induced oscillations (PIOs) during recovery." The report said that the NTSB was also aware of three MD-11 incidents in which turbulence upsets resulted in PIOs during recovery. " In all of the cases, the autopilot was engaged at the beginning of the upset, and the stall warning system activated repeatedly through the PIO. Analysis of the cases suggests that the PIOs during recovery from the pitch attitude upsets are, in part, due to excessive and prolonged control movements by the pilot in reaction to the stall warning system activations," the report said.

The NTSB expressed concern that MD-11 pilots were not receiving specific training related to high-altitude upsets and stall warnings. "The MD-11 is designed to fly with minimal longitudinal stability margin to improve the economic performance of the airplane. The control column forces needed for manually controlling the airplane during normal maneuvers in cruise flight are lighter than those that pilots might have encountered in their past experiences in other model airplanes, and they are considerably lighter than the control forces normally used at lower speeds and altitudes," the report said.

The report said, "DAC recommends that the airplane be operated at lower altitudes to increase the stall margin if high-altitude turbulence is encountered. The DAC recommendation would result in a +1.4 g to +1.5 g stall margin while improving the economic operation of the airplane, a goal of operating at relaxed stability, the report said. According to DAC, the FAA has no certification requirement for high-altitude stall margins, while the European Joint Airworthiness Authorities require that airplanes be operated with at least a 1.3 g margin. The Safety Board believes that a greater stall margin would provide the MD-11 with enhanced protection from unsafe pitch oscillations following turbulence and slat deployment-induced pitch upsets.

"Improved MD-11 pilot training and the scheduled redesign of the MD-11 flap/slat actuation system may reduce the number of MD-11 pitch attitude upsets and resulting PIOs. The MD-11's longitudinal stability, stall warning margin, stall buffet damage susceptibility, and pilot training must undergo a thorough review to ensure that routine pitch attitude upsets do not result in stall warning system deactivations, overcontrol-induced oscillations, structural damage, or any other condition that could lead to unsafe flight," the report added.

As a result of its investigation, the NTSB made the following safety recommendations to the FAA:

- "Require Douglas Aircraft Company to provide data needed to upgrade MD-11 training simulators to accurately represent the aircraft's longitudinal stability and control characteristics for high-altitude cruise flight; and to develop specific guidance and simulator scenarios to train pilots in optimum techniques for the recovery from high-altitude upsets, including those accompanied by stall warning;

- "Require operators to provide specific training for the recovery from high-altitude upsets, including those accompanied by stall warning;

- "Establish high-altitude stall margins for MD-11 airplanes in order to limit the effects of high-altitude pitch upsets;

- "Evaluate the dynamics of the MD-11 stall warning system to ensure that the 'on' and 'off' logic are consistent with providing the pilot timely information;

- "Conduct a thorough review of the MD-11 high-altitude cruise longitudinal stability and control characteristics, stall warning margins, and stall buffet susceptibility to ensure that pilot response to routine pitch attitude upsets do not result in hazardous pitch oscillations, structural damage, or any other condition that could lead to unsafe flight;

- "Issue an AD requiring the operators of MD-11s to install an interim flap/slat handle system or device to prevent the inadvertent deployment of the wing leading edge slats, when such a device becomes available;

- "Issue an air carrier operations bulletin to FAA principal operations inspectors to verify that MD-11 operators have advised flight crews of the potential for an inadvertent inflight slat extension if contact is made with the flap/slat handle;" and,

- "Require an expeditious installation of a redesigned flap/slat actuating system, when it becomes available for retrofit, that will prevent uncommanded and inadvertent deployment of the leading edge wing slats on MD-11 airplanes."

... a greater stall margin would provide the MD-11 with enhanced protection from unsafe pitch oscillations following turbulence and slat deployment-induced pitch upsets.

In response to these recommendations, the FAA issued an AD "that requires the installation of a retainer assembly on the upper pedestal flap/slat control module quadrant in the flight compartment. … This AD is intended to prevent inadvertent slat deployment during flight at cruise altitude," the report said.

The FAA said it would "issue an air carrier operations bulletin to direct FAA principal operations inspectors to have their assigned MD-11 operators inform all flight crews of the potential for an inadvertent inflight slat extension if contact is made with the flap/slat handle." The FAA also stated that it is working with DAC "to expedite the review, approval and installation of the redesigned flap/slat actuation system."

The investigation revealed that although it did not contribute to this accident, "the fire-blocking material under the dress covers of the passenger seat cushions had deteriorated to an extent that the material no longer provided fire protection to the seat cushions," the report said. "Samples of fire-blocking material removed from the accident airplane, an ATR-42 that is currently being flown by a U.S. air carrier and a new sample of the fire-blocking material, supplied by the manufacturer, failed to meet the standards set forth in [Federal Aviation Regulations (FAR) Part 25.853]."

The report said that the material degraded under normal usage (in two years on the accident airplane) and under simulated wear-and-tear conditions that equated to two years in service. "Based on the findings of the postaccident testing of this fire-blocking material, the Safety Board believes that all transport category aircraft manufactured or operating in the United States that have seat cushions covered with Testori-manufactured fire-blocking material may not meet the airworthiness requirements of Part 121.312 and Part 25. Consequently, the FAA should develop a requirement for verifying the integrity of the material. If the material is found to be defective, it should be removed from service," the report said.

"The FAA should inform operators of the need to periodically inspect fire-blocking materials for wear and damage and to replace unserviceable materials," the report said. Part 25.853 should, in addition to requiring current burn tests of fire-blocking materials, require burn tests of like materials that have been subject to wear that simulates in-service wear, the report said. "This … test would serve to establish the service life of the material," the report said.

The report said that the fire-blocking material manufactured by Testori "is currently being used on thousands of aircraft seats in the commercial aircraft fleet around the world. In the United States, the FAA has established definitive fire-retardant standards for seats used on commercial aircraft. However, Annex 8 of the International Civil Aviation Organization (ICAO) International Standards, Airworthiness of Aircraft, does not set forth any uniform standards or recommended inspections/practices.

"The Safety Board believes that the FAA should inform other certification authorities about the need for monitoring the airworthiness of the fire-retardant properties of the seats that are used on airliners worldwide," the report said.♦

Editorial Note: This article was adapted from *Aircraft Accident Report, Inadvertant In-Flight Slat Deployment China Eastern Airlines Flight 583, McDonnell Douglas MD-11, B-2171, 950 Nautical Miles South of Shemya, Alaska, April 6, 1993,* prepared by the U.S. National Transportation Safety Board. The 64-page report includes illustrations and appendices.

About the Author

Russell Lawton is an aviation safety consultant, a U.S. Federal Aviation Administration accident prevention counselor and editor of IFR Refresher *magazine. Lawton is the former vice president of operations for the Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation and served on the International Civil Aviation Organization (ICAO) Personnel Licensing and Training panel. Lawton holds an airline transport pilot certificate and a flight instructor's certificate and has logged more than 5,000 flight hours.*

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