National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 10, 2011

In reply refer to: A-11-7 through -11

The Honorable J. Randolph Babbitt
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On June 14, 2009, about 1817 Coordinated Universal time, a Boeing 737-400 (737), registration number TC-TLA, operated as Tailwind Airlines flight OHY036, experienced an uncommanded pitch-up event at 20 feet above the ground during approach to Diyarbakir Airport (DIY), Diyarbakir, Turkey.[1] The flight crew performed a go-around maneuver and controlled the airplane's pitch with significant column force, full nose-down stabilizer trim, and thrust. During the second approach, the flight crew controlled the airplane and landed by inputting very forceful control column inputs to maintain pitch control. Both crewmembers sustained injuries during the go-around maneuver; none of the 159 passengers or cabin crewmembers reported injuries. The airplane was undamaged during the scheduled commercial passenger flight. The Turkish Directorate General of Civil Aviation, acting on behalf of the State of Occurrence, delegated the investigation to the National Transportation Safety Board (NTSB). The NTSB investigated this incident under the provisions of International Civil Aviation Organization Annex 13 as the Country of Manufacture and Design of the airplane.

The NTSB's investigation found that the incident was caused by an uncommanded elevator deflection as a result of a left elevator power control unit (PCU) jam due to foreign object debris (FOD). The FOD was a metal roller element (about 0.2 inches long and 0.14 inches in diameter) from an elevator bearing. During its investigation of this incident, the NTSB identified safety issues relating to the protection of the elevator PCU input arm assembly, design of the 737 elevator control system, guidance and training for 737 flight crews on a jammed elevator control system, and upset recovery training.

[1] More information regarding this incident, National Transportation Safety Board case number ENG09IA011, is available online at <http://www.ntsb.gov/ntsb/query.asp>.

Protection of the Elevator PCU Input Arm Assembly

Boeing 737-300 through -500 series airplanes'[2] primary pitch control[3] is provided by two hydraulically powered elevators with manual reversion[4] available in the event of a loss of hydraulics. The elevators are controlled by forward and aft motion of the captain's and first officer's control columns, which are connected to each other via a torque tube with a forward cable control quadrant mounted at each end. Elevator control cables are routed from the quadrants' aft end and attach to a pair of aft elevator control quadrants, which are mounted on the lower elevator input torque tube.[5] This tube is mechanically connected, via linkages, to each PCU input arm assembly, which, when rotated, provides a simultaneous command to each PCU to extend or retract.[6] The output rod of each PCU is connected to the upper torque tube, which is directly linked by pushrods to each elevator (see figure). The elevator PCUs are located in the tail of the airplane.

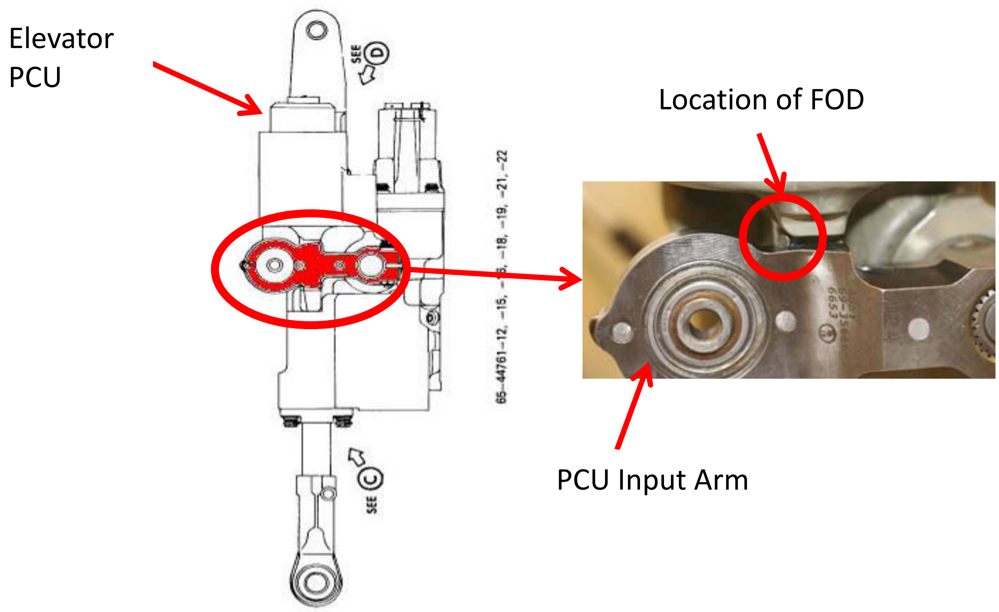

Figure. Location of FOD.

[2] While 737-100 and -200 series airplanes are similar in design to 737-300 through -500 series airplanes, the NTSB notes that 737-100 series airplanes are no longer in service, and 737-200 series airplanes are no longer operated by U.S. carriers.

[3] The design of the 737-600 through -900 series airplanes' pitch control system is different from that on 737-300 through -500 series airplanes; these differences are discussed in the "Design of the 737 Elevator Control System" section of this letter.

[4] "Manual reversion" means "without hydraulic power." In manual reversion mode, the pilot can control the elevators and ailerons by movement of the control column or wheel, respectively, but the control forces will be much higher than with hydraulics.

[5] The aft elevator controls are located in the empennage aft of the stabilizer rear spar.

[6] The two PCUs operate in unison, and each is powered by a separate and independent hydraulic system (the left unit from hydraulic system "A" pressure and the right unit from hydraulic system "B" pressure).

Tailwind Airlines' postincident inspection of the elevator PCUs revealed that the system "A" elevator PCU input arm assembly was jammed by a piece of FOD (a metal bearing roller) in a position that offset the control arm in a downward direction. With the control arm deflected downward and with hydraulic pressure available, the PCU would be commanded to move the elevator to a position that would pitch the aircraft nose up. The incident airplane's flight data recorder (FDR) recorded an aircraft pitch up during the landing flare just before the commanded go-around maneuver. Because of the way the elevators are linked together, a jam in one PCU will cause both elevator surfaces to deflect in the same direction. (The two sides of the system cannot be disconnected so that the unjammed PCU can control the elevators.)

In January 2009, a scheduled maintenance check ("C" check) was performed on the airplane. Part of the check involved replacement of the upper torque tube output crank bearing. Postincident inspections of the airplane's elevator system components located within the tailcone also revealed that the left elevator upper torque tube output crank bearing/sleeve appeared new, with all bearings present. The NTSB determined that, at some point during maintenance or in-service operation before the January 2009 maintenance check, metal rollers[7] became dislodged from the bearing and scattered throughout the aft elevator system components.

During its investigation of this incident, the NTSB noted that the 737 aileron control system uses PCUs identical to those located in the elevator control system. FOD contamination is considered more likely in the aileron control system due to the location of the aileron PCUs in the main landing gear (MLG) wheel well. This area is exposed to the external environment whenever the MLG is extended, and the flight control components are vulnerable to damage from environmental debris or tire failure. Protective modifications had to be accomplished[8] on specified flight control components located in the wheel well. Two of these components, the aileron PCUs, were modified by the incorporation of protective soft covers over the input arm assembly of each aileron PCU.

The NTSB notes that the protective covering used for the aileron input arm assemblies would likely also help protect the elevator PCUs on 737-300 through -500 series airplanes from FOD. The NTSB concludes that FOD within any flight control system is a serious concern because debris may migrate and become lodged within the controls, resulting in a jam of the control system during a critical phase of flight. Further, the NTSB concludes that special protection (in the form of protective covering or other methods) for the elevator PCUs would ensure that FOD does not jam the elevator PCU input arm assembly. Therefore, the NTSB recommends that the Federal Aviation Administration (FAA) require Boeing to develop a method to protect the elevator PCU input arm assembly on 737-300 through -500 series airplanes from FOD. The NTSB further recommends that the FAA, once Boeing has developed a method to protect the elevator PCU input arm assembly on 737-300 through -500 series airplanes from

[7] In addition to the metal bearing roller that caused the jam, a second metal bearing roller was found resting at the bottom of the tailcone near the drain hole, mostly buried in debris. Boeing's metallurgical analysis revealed that both metal bearing rollers had the same dimensions and material as the rollers that are installed in two locations in the aft elevator control system (the right and left ends of the elevator upper output torque tube crank assembly).

[8] In July 1987, Boeing issued Service Bulletin 737-52-109 to remove the MLG wheel well tire burst protector screen doors on all 737 airplanes that are so equipped. The Federal Aviation Administration (FAA) did not issue an airworthiness directive to mandate this service bulletin. For more information, see FAA B737 Flight Control System Critical Design Review, dated May 3, 1995.

FOD as requested in Safety Recommendation A-11-7, require operators to modify their airplanes with this method of protection.

Design of the 737 Elevator Control System

The NTSB's investigation of this incident revealed that the flight crew controlled the airplane through the use of full nose-down stabilizer trim, thrust, and effort by both crewmembers to resist the pull action caused by the jam. The forces required to control the airplane were so high that the crewmembers' exertions on the control column resulted in their injuries. The design of the 737-300 through -500 series airplanes does not include any means by which the flight crew can override an elevator control system jam. During its investigation of this incident, the NTSB reviewed the design history of these airplanes, the potential for additional jamming events, and the jam override mechanisms available on other airplane models.

According to the FAA's service difficulty report database, four additional 737-300 through -500 series airplanes experienced events involving binding or jamming of the elevator control system. Although none of these events resulted in an accident, they highlight the fact that binding or jams of the elevator system do occur in flight, can result from numerous causes (including improper maintenance performed on the airplane), and can present the flight crew with controllability hazards. During the first reported event, which occurred on January 14, 1998, the flight crew indicated that the elevator jammed while flaring the airplane for landing and required approximately 50 to 60 pounds of force on the columns to free the elevators. The source of the jam could not be identified. The second reported event occurred on October 12, 2003, during which the flight crew reported stiff controls throughout the flight, and, during the landing flare, the control column bound for a moment and then broke free. The source of the jam could not be identified. During the third reported event on October 16, 2003, the flight crew indicated that the elevator was binding when pulling the control column back to the point of having to use excessive pressure to return the column to neutral. The flight crew reported that the column was completely stuck at one point in the flight. Maintenance crews found a large piece of Velcro lodged between an elevator cable pulley and cable retainer. The elevator system was cycled and found to operate normally after the removal of the Velcro. During the fourth reported event on October 9, 2005, the flight crew aborted takeoff at 140 knots due to no elevator movement. Maintenance personnel discovered that the elevator balance weight from one elevator was lodged between the lower surface of the elevator and the stabilizer, resulting in a jam that prevented both elevators from moving. If this jam had occurred during flight instead of during the takeoff roll, control of the airplane would have been extremely difficult. These reports indicate that jams of the 737 elevator system occur during service, and because the jammed portions of the system cannot be overridden, the flight crews have no option but to try to overpower the jam with excessive force.

Further, a design review of the 737 elevator system has determined that there are additional ways in which the system may become jammed. The NTSB's query of the FAA's airworthiness directive (AD) database revealed that, on November 25, 2005, the FAA issued AD 2005-26-03, "Elevator Input Torque Tube Assembly," for all 737s (737-100 through -900 series airplanes) to prevent the loss of elevator control and subsequent reduced controllability. The AD resulted from a report of a restriction in the pilot's elevator input control system.

Although the cause of the incident was not determined, a design review that Boeing performed on the aft elevator input torque tube assembly during the investigation revealed possible failure modes that could lead to an elevator control system jam. The FAA issued the AD to require operators to take action to prevent these jams.

The NTSB reviewed the 737-300 through -500 series airplane certification requirements and found that even though these airplanes were awarded type certificates between 1984 and 1990, the elevator control system of the 737-300 through -500 series airplanes was considered to be unchanged and carries the same certification basis as the 737-100 and -200 series airplanes (which were certified in 1967).[9] The NTSB's review of the certification data also revealed that even though Boeing had developed flight control system designs that included jam override mechanisms for use in other airplanes before the certification of the 737-300 through -500 series airplanes (such as the 757 and 767 airplanes, which were introduced into service in 1983 and 1982, respectively), these designs were not incorporated into the 737-300 through -500 series airplanes and were not required to be by the FAA.

The NTSB notes that during discussions with the FAA and Boeing regarding elevator jamming incidents, all parties agreed that a jam in the elevator system (either a rate jam or position jam) should be considered a catastrophic hazard. Further, given the age of the 737-300 through -500 series airplanes, the need for maintenance actions in critical areas of the flight control system should be expected to grow, further increasing the possibility of jam-inducing failures caused by FOD, maintenance errors, or other failures which by today's certification standards would require that no single failure in the control system be able to contribute to such a jam. As a result, the NTSB believes that additional design improvements should be considered to mitigate the effects of single-point-induced jams.

The elevator control system on 737-300 through -500 series airplanes comprises two parallel sets of flight control cables (one connected to the captain's side and the other to the first officer's side) that transmit flight control commands from the control columns to the aft elevator input torque tube and then to the elevator PCU input arm via control rods. Because the system does not contain override mechanisms, a single point malfunction (jam) to one side of the control system will effectively jam both sides of the control system, resulting in the partial or complete loss of elevator control. In such a scenario, the flight crewmembers may not be able to exert enough force on both control columns to overcome the jam and would therefore lose control of the elevators.

A review of the elevator control systems on other transport-category airplanes indicates that override mechanisms are commonly installed and aid in maintaining control of the airplane when a system malfunction occurs. For example, Boeing 717, 747, 757, 767, and 777 airplanes; Embraer 120, 145, 170, and 190 airplanes; Bombardier Canadair Regional Jet CRJ-200, CL-600-2B19, DHC-8, and Q400 airplanes; and ATR-42 and -72 airplanes all contain override mechanisms in the elevator system. Further, the elevator system on 737-600 through -900 series airplanes was improved by the addition of several mechanical override mechanisms. While these

[9] When the 737-100 and -200 series airplanes were certified, 14 *Code of Federal Regulations* Part 25 did not specifically require consideration of a jam resulting from a single failure mode of a device in the control system as long as the failure mode was considered extremely remote.

override mechanisms do not mitigate all possible jam conditions, in general, in the event of a system jam, the mechanisms allow both elevators to be controlled by the movement of the unaffected control column.

The following September 2, 2004, event involving a de Havilland (Bombardier) DHC-8 airplane highlights the benefit of an override mechanism for the elevator control system.[10] The Transportation Safety Board of Canada reported that, during the initial climb following takeoff, the first officer noted that abnormal forward pressure on the control column was required to keep the airplane from pitching nose up. To counter the pitch-up, he trimmed the airplane nose down. About 30 seconds after becoming airborne, the airplane was 350 feet above ground level, and the first officer had applied full nose-down trim. The amount of forward pressure on the control column continued to increase as the airplane accelerated, and the first officer notified the captain of the control difficulties and requested his assistance in holding the control column forward. The flight crew leveled the airplane at 4,000 feet above sea level and pulled the elevator pitch disconnect handle, isolating the left and right elevators. The captain's elevator control functioned normally after the disconnect, and he continued the flight.[11]

Because of the lack of an override mechanism within the elevator control system on the 737-400 airplane involved in the Tailwind Airlines incident, the flight crewmembers had to exert constant and excessive force on the control columns to overcome the jam. While the flight crewmembers exerted enough force on the control columns to overcome the jam, the NTSB is concerned that other jam scenarios may exist in which pilot inputs would not be enough to successfully control the airplane. Consequently, there may be no assurance of continued safe flight and landing in the event of an elevator control system jam. The NTSB concludes that because the elevator control system on 737-300 through -500 series airplanes does not contain any override mechanisms, a single-point jam-type failure (restriction of any elevator control system components) could result in the loss of elevator system control and could render the airplane uncontrollable. Therefore, the NTSB recommends that the FAA require Boeing to redesign the 737-300 through -500 series airplane elevator control system such that a single-point jam will not restrict the movement of the elevator control system and prevent continued safe flight and landing. The NTSB further recommends that the FAA, once the 737-300 through -500 series airplane elevator control system is redesigned as requested in Safety Recommendation A-11-9, require operators to implement the new design.

Guidance and Training for 737 Flight Crews on a Jammed Elevator Control System

The NTSB determined that the elevator control system on the incident airplane was functioning normally during the flight until the final approach to runway 34 at DIY. FDR data indicated that, about 20 feet above the ground, there was an uncommanded deflection of both

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[10] For more information, see *Flight Control Difficulties, Jazz Air Inc., de Havilland DHC-8-102 C-FGRP, Kingston, Ontario, 02 September 2004*, Aviation Investigation Report A04O0237 (Gatineau, Quebec, Canada: Transportation Safety Board of Canada, 2005).

[11] An inspection after landing revealed that half of one of the balance weights from the right-side elevator spring tab and the nuts that secured it were missing. The two bolts had jammed on the top surface of the elevator and held the elevator spring tab in the trailing-edge-down position.

elevators, resulting in the airplane's pitch attitude increasing from about 4° to about 40° within about 14 seconds. The flight crew reacted immediately to the uncommanded pitch-up event by adjusting the stabilizer trim position to its full nose-down position (0 units) and by attempting to move the elevator control columns forward. FDR data indicated that, once the flight crewmembers reestablished minimal control over the pitching tendency, they turned off the hydraulic power to the flight controls. This action removed the hydraulic pressure from both elevator PCUs, resulting in both elevators deflecting to their neutral (zero hinge moment or float) position. Because the flight crew had just positioned the stabilizer to its full aircraft nose-down position, without the counteracting force of the elevator, the airplane's pitch attitude rapidly changed from +5° to about -5°. The flight crew immediately restored hydraulic power, and the airplane continued to demonstrate significant pitch-up tendencies. The flight crew ultimately controlled the airplane through the use of full nose-down stabilizer, thrust, and effort by both crewmembers on the column.

The flight crewmembers did not have sufficient time to reference the 737 flight crew operations manual (FCOM) or Quick Reference Handbook (QRH). The 737 FCOM provides general guidance for a jammed or restricted flight control and states, in part, that "if any jammed flight control condition exists, both pilots should apply force to try to either clear the jam or activate the override feature." Because the 737-400 does not have a mechanical override feature for a jammed elevator, the pilots needed to try to clear the jam. However, the NTSB's review of the 737 FCOM revealed that there are no checklists or procedures regarding recovery from an uncommanded elevator deflection and/or a jammed elevator control system.

The NTSB notes that an airplane with flight control problems should be handled in a slow, methodical manner by managing the airplane's energy, arresting the flightpath divergence, and recovering to a stabilized flightpath before referencing any written guidance (such as an FCOM, QRH, or quick reference checklist). As demonstrated on the incident flight, when the flight crew turned off hydraulic power, the position of the elevators changed, causing a change in the airplane's pitch attitude due to the nose-down pitch trim that the flight crew had previously applied. The flight crew's immediate actions after the jam of the elevator PCU allowed them to stabilize the airplane to make a go-around maneuver; however, by turning off the hydraulic power during the go-around maneuver, the flight crew adversely affected the airplane's controllability.

The NTSB concludes that, without guidance to flight crews regarding appropriate actions to take in the event of an inoperative or malfunctioning elevator control system, pilots may improvise troubleshooting measures that could inadvertently worsen the condition of a marginally controllable airplane.[12] Therefore, the NTSB recommends that the FAA require Boeing to develop recovery strategies (for example, checklists, procedures, or memory items) for

[12] This was an issue in the January 31, 2000, crash of Alaska Airlines flight 261 into the Pacific Ocean near Anacapa Island, California. Following that accident, the NTSB issued Safety Recommendation A-02-36, which asked the FAA, in part, to "issue a flight standards information bulletin directing air carriers to instruct pilots that in the event of an inoperative or malfunctioning flight control system, if the airplane is controllable they should complete only the applicable checklist procedures and should not attempt any corrective actions beyond those specified." This recommendation was classified "Closed—Acceptable Action" on January 13, 2005.

pilots of 737 airplanes that do not have a mechanical override feature for a jammed elevator in the event of a full control deflection of the elevator system and incorporate those strategies into pilot guidance. Within those recovery strategies, the consequences of removing all hydraulic power to the airplane as a response to any uncommanded control surface should be clarified.

Upset Recovery Training

On October 18, 1996, the NTSB issued Safety Recommendation A-96-120 in response to three uncommanded roll and/or yaw events that occurred while 737 airplanes were approaching to land: the March 3, 1991, United Airlines flight 585 accident in Colorado Springs, Colorado; the September 8, 1994, USAir flight 427 accident near Aliquippa, Pennsylvania; and the June 9, 1996, Eastwind Airlines flight 517 incident in Richmond, Virginia. Safety Recommendation A-96-120 asked the FAA to do the following:

> Require 14 [*Code of Federal Regulations*] CFR Part 121 and 135 operators to provide training to flight[ ]crews in the recognition of and recovery from unusual attitudes and upset maneuvers, including upsets that occur while the aircraft is being controlled by automatic flight control systems, and unusual attitudes that result from flight control malfunctions and uncommanded flight control surface movements.

On January 16, 1997, the FAA responded that many operators are currently providing training on the recognition, prevention, and recovery of aircraft attitudes normally not associated with air carrier flight operations. On August 11, 1999, the FAA indicated that it initiated a notice of proposed rulemaking (NPRM) proposing to revise 14 CFR Part 121, Subparts N and O, to include training in the recognition of and recovery from unusual attitudes and upset maneuvers. The FAA anticipated that the NPRM would be published in December 2000. The FAA later indicated that the NPRM might be published in 2003. The NPRM was published in 2009; however, to date, no regulation has been enacted based on the NPRM.

On October 26, 2004, the NTSB reclassified Safety Recommendation A-96-120 "Open—Unacceptable Response" as part of its report on the crash of American Airlines flight 587 in Belle Harbor, New York.[13] The NTSB notes that 14 years have passed since the issuance of this recommendation, and the FAA has yet to make regulatory changes to address this safety issue. However, the Tailwind Airlines incident supports the need for flight crew training in the recognition of and recovery from unusual attitudes and upset maneuvers. Any training reference material that the FAA uses for upset recovery training course curriculum development should include a description of jammed or restricted flight controls, along with a description of how best to incorporate those recovery strategies to a control malfunction similar to that which occurred in the Tailwind Airlines incident.[14] Such training would likely have provided the incident flight crew with critical information about how to recover from a jammed elevator

[13] See *In-Flight Separation of Vertical Stabilizer, American Airlines Flight 587, Airbus Industrie A300-605R, N14053, Belle Harbor, New York, November 12, 2001,* Aircraft Accident Report NTSB/AAR-04/04 (Washington, D.C.: National Transportation Safety Board, 2004).

[14] Although Tailwind Airlines is not a U.S. carrier, the 737 is used extensively by U.S. carriers with FAA oversight.

control system. The NTSB notes that the initial actions by the flight crew to return the airplane to controllable flight were consistent with the techniques defined in the *Airplane Upset Recovery Training Aid*.[15] The NTSB believes this incident emphasizes the importance of the upset training as recommended in Safety Recommendation A-96-120 so that flight crewmembers can be provided with skills to employ during an airplane upset.

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

> Require Boeing to develop a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris. (A-11-7)
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> Once Boeing has developed a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris as requested in Safety Recommendation A-11-7, require operators to modify their airplanes with this method of protection. (A-11-8)
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> Require Boeing to redesign the 737-300 through -500 series airplane elevator control system such that a single-point jam will not restrict the movement of the elevator control system and prevent continued safe flight and landing. (A-11-9)
>
> Once the 737-300 through -500 series airplane elevator control system is redesigned as requested in Safety Recommendation A-11-9, require operators to implement the new design. (A-11-10)
>
> Require Boeing to develop recovery strategies (for example, checklists, procedures, or memory items) for pilots of 737 airplanes that do not have a mechanical override feature for a jammed elevator in the event of a full control deflection of the elevator system and incorporate those strategies into pilot guidance. Within those recovery strategies, the consequences of removing all hydraulic power to the airplane as a response to any uncommanded control surface should be clarified. (A-11-11)

In response to the recommendations in this letter, please refer to Safety Recommendations A-11-7 through -11. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our secure mailbox. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

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[15] *Airplane Upset Recovery Training Aid, Revision 1,* Page 3, B-65, states that nose-high, wings-level recovery techniques (pitch attitude unintentionally more than 25°, nose-high and increasing, airspeed decreasing rapidly, ability to maneuver decreasing) include the following: recognize and confirm the situation, disengage autopilot and autothrottle, apply as much as full nose-down elevator, use appropriate techniques, roll to obtain a nose-down pitch rate, reduce thrust (underwing-mounted engines), complete the recovery, approach horizon, roll to wings level, check airspeed and adjust thrust, and establish pitch attitude.

Chairman HERSMAN, Vice Chairman HART, and Members SUMWALT, ROSEKIND, and WEENER concurred in these recommendations.

[Original Signed]

By: Deborah A.P. Hersman
Chairman