Log # 2304A

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: October 18, 1996

In reply to refer to: A-96-107 through -120

Honorable David R. Hinson
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On March 3, 1991, United Airlines flight 585, a Boeing 737-291 (B-737-200), N999UA, crashed while maneuvering to land at Colorado Springs Municipal Airport, Colorado Springs, Colorado. The airplane was being operated on an instrument flight rules (IFR) flight plan under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121, as a regularly scheduled flight from Denver, Colorado, to Colorado Springs. The airplane was destroyed by impact forces and fire; all 25 persons on board were killed. The National Transportation Safety Board was unable to determine the cause of the accident; however, the Board found it likely that either a malfunction of the airplane's lateral or directional control system or an encounter with an unusually severe atmospheric disturbance resulted in the sudden uncontrollable lateral upset.

On September 8, 1994, USAir flight 427, a Boeing 737-3B7 (B-737-300), N513AU, crashed while maneuvering to land at Pittsburgh International Airport, Pittsburgh, Pennsylvania. The airplane was being operated on an IFR flight plan under 14 CFR Part 121, as a regularly scheduled flight from Chicago, Illinois, to Pittsburgh. The airplane was destroyed by impact forces and fire; all 132 persons on board were killed. The Safety Board has not completed the investigation of this accident.

On June 9, 1996, Eastwind Airlines flight 517, a Boeing 737-200, N221US, experienced a roll/yaw upset on approach to land at Richmond Airport, Richmond, Virginia. The airplane was being operated on an IFR flight plan under 14 CFR Part 121, as a regularly scheduled flight from Trenton, New Jersey, to Richmond. The airplane was not damaged, and no one was injured. The Safety Board has not completed the investigation of this incident; however, the investigation has determined that at the start of the upset, there was an uncommanded rudder displacement that exceeded the normal operating limits of the yaw damper system.

Since the accident involving United flight 585, the Safety Board has been informed of numerous uncommanded roll and yaw events involving the Boeing 737 series. Although most of these incidents did not result in any damage to the airplane or injuries to those on board, the

Safety Board examined flight data recorder (FDR) information and flight control components in many of the events.

The investigations of the above accidents and incidents have involved extensive examinations of the B-737's flight control systems and flightcrew procedures. It is noted that the accidents involving United flight 585 and USAir flight 427 and the incident involving Eastwind flight 517 occurred following roll and/or yaw excursions while the aircraft were approaching to land. Although comprehensive testing and examinations have not identified any anomalies with either the United flight 585 or USAir flight 427 flight control systems or components that could have caused the accidents, the Safety Board has identified safety issues involving the B-737 series aircraft that need to be addressed by the Federal Aviation Administration (FAA) to improve the safety of the B-737 series aircraft.

On October 20, 1994, the FAA Transport Airplane Directorate was chartered by the Administrator of the FAA to conduct a critical design review (CDR) of the B-737 flight control system with emphasis on the lateral and directional flight control systems (the aileron/flight spoiler and rudder systems, respectively). The review was conducted by a team of FAA flight control systems specialists with the overall objective to confirm the continued operational safety of the B-737.

The CDR team's effort paralleled a portion of the Safety Board's investigation of the B-737 flight control system. The CDR team's charter provided that it review potential failures in the B-737 flight control system without regard to their probability of occurrence and without consideration of the airplane's certification basis. A final report that contained 27 recommendations was issued on May 3, 1995.[1]

As a result of seven of these recommendations, on August 22, 1996, the FAA issued notices of proposed rulemaking (NPRMs) for nine airworthiness directives (ADs) concerning components in the flight control system of the B-737 series. Two of the proposed ADs address concerns of the Safety Board that will be discussed in this letter. These and other concerns raised by the FAA's CDR team are areas in which the Safety Board believes improvements can be made.

Lateral Controllability

The CDR team report stated that there are "a number of ways where loss of rudder control and potential for a sustained rudder hardover may occur.... Since full rudder hardovers[2] and/or jams are possible, the alternate means for control, the lateral control system, must be fully available and powerful enough to rapidly counter the rudder and prevent entrance into a hazardous flight condition."[3]

---

[1]Federal Aviation Administration--B737 Flight Control System Critical Design Review Report, May 3, 1995.

[2]A control surface hardover is defined as an uncommanded, sustained deflection of the control surface to its full travel position.

[3]Federal Aviation Administration--B737 Flight Control System Critical Design Review Report, May 3, 1995, p. 16.

While there are insufficient data regarding the Colorado Springs accident to resolve whether a deflection of the rudder was a factor in the accident, the data for USAir flight 427 accident strongly suggest that the airplane yawed and rolled in response to a deflection of the airplane's rudder coincident with the encounter of a wake vortex, and the data for the Eastwind accident support rudder involvement. However, the Safety Board has not found evidence in any accident or incident of a failure of the B-737 directional control system that could have caused an uncommanded rudder deflection. Figure 1 provides a depiction of the B-737 rudder system and the main rudder power control unit (PCU).

At the Safety Board's January 1995 public hearing for the USAir flight 427 accident, Boeing Commercial Airplane Group and FAA engineers testified that engineering simulations and flight test data showed that the B-737 airplane was controllable at the airspeeds recorded by the FDR at the time of USAir flight 427's initial upset. The testimony also indicated that with a fully deflected rudder surface, sufficient lateral control capability existed to safely control the airplane's flightpath.

Simulator tests conducted by the CDR team determined the following:

> These tests basically confirmed Boeing's contention that lateral control has more roll authority than does the dihedral effect from full rudder inputs for flight conditions tested except the flaps 1,[4] 190 KIAS [knots indicated airspeed] condition. For this condition lateral control also predominated, but recovery from a rudder "hardover" was slow and required precise pilot control of resulting pitch/airspeed. Prompt pilot response was required to prevent entering the inverted regime at high altitude/speed.[5]

The CDR team recommended the following to the FAA's Seattle Aircraft Certification Office:

> [E]nsure that the capability of the B737 lateral control system to provide adequate directional control is clearly demonstrated throughout the airplane operating envelope after these failures, unless they are shown to be extremely improbable[6] by the most rigorous methodology available.[7]

In support of the USAir flight 427 accident investigation, the Safety Board, with the participation of USAir, Boeing, the Air Line Pilots Association (ALPA), the FAA, and the National Aeronautics and Space Administration (NASA), conducted flight tests to examine the

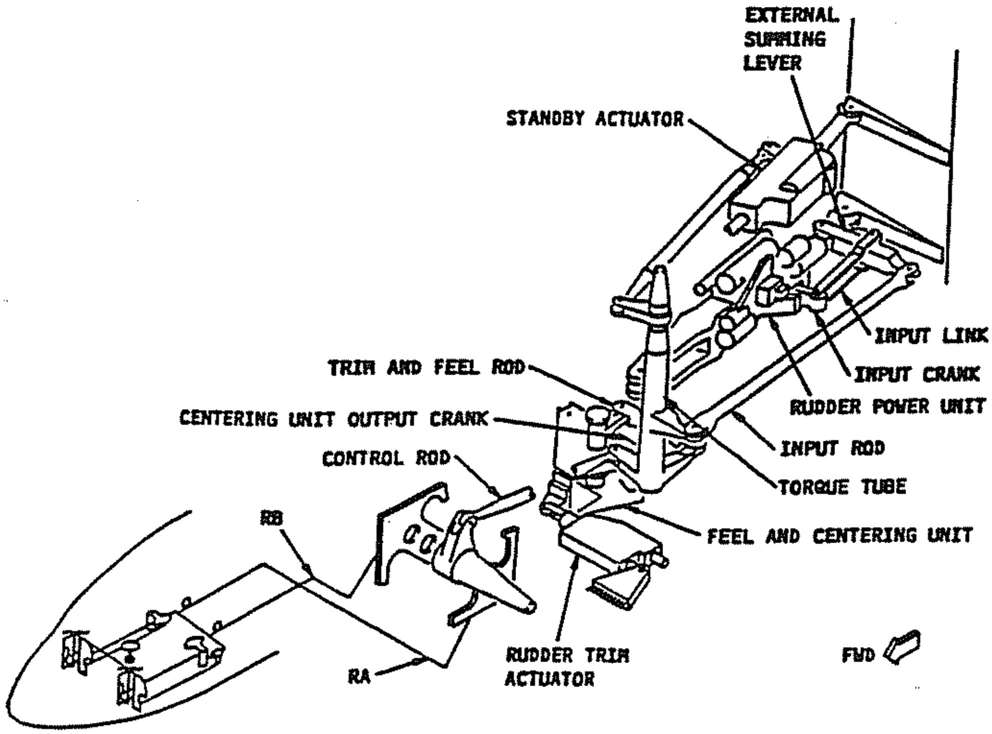
---

[4]The flaps 1 setting provides for extension of the wing leading edge slats and flaps and 1^0 of the wing trailing edge flaps.

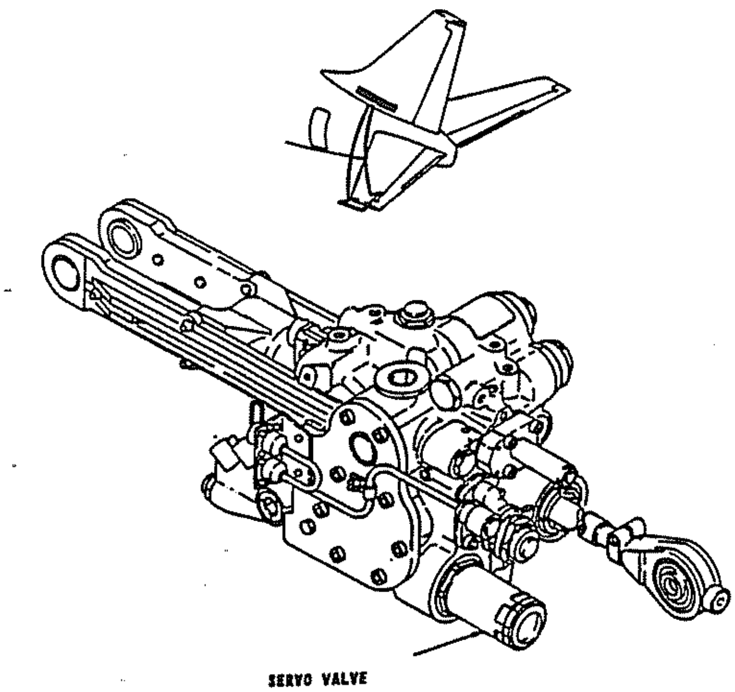
[5] Federal Aviation Administration--B737 Flight Control System Critical Design Review Report, May 3, 1995, p. 12.

[6]"Extremely improbable" is defined in FAA Advisory Circular 25.1309-1A as a probability of failure of 1×10^{-9} or less for each flight hour.

[7] Federal Aviation Administration--B737 Flight Control System Critical Design Review Report, May 3, 1995, p. 36.



B-737 RUDDER SYSTEM



B-737 MAIN RUDDER POWER CONTROL UNIT

Figure 1. B-737 Rudder System and Main Rudder Power Control Unit

aerodynamic effects of B-727-generated wake vortices on a B-737-300 airplane. Before the wake vortex flight tests, a B-737 airplane was flown at a flaps 1 setting and airspeeds from 150 knots calibrated airspeed (KCAS) to 225 KCAS to acquire additional data to refine the B-737 engineering simulator. In one of the tests, the pilots attempted to maintain a constant (or steady) heading by using the control wheel to oppose full rudder surface deflections. These tests found that at certain airspeeds and aircraft configurations, there was insufficient lateral control to completely counter the roll effects of a fully deflected rudder. Roll control was attained by lowering the nose and increasing the airspeed.

Analysis of the flight test data indicated that at flaps 1 and airspeeds of about 190 KCAS or more, the roll induced by a full rudder deflection could be controlled by control wheel input. However, at airspeeds below 190 KCAS and flaps 1, the roll induced by a full rudder deflection could not be eliminated by full control wheel input. With the rudder fully deflected and decreasing airspeeds, the airplane rolled into the direction of the rudder deflection. The tests also indicated that the test airplane's rudder traveled slightly farther before reaching aerodynamic blowdown[8] than originally predicted by Boeing.

The Safety Board is concerned that at low altitudes, on approach, or in instrument weather conditions, there may be insufficient time for pilots to react to rudder hardovers or large deflections. In such conditions, any reduction in the time available for a successful recovery increases the potential for an accident. Based on this concern and the above-mentioned flight test data, the Safety Board believes that the FAA should require Boeing, working with other interested parties, to develop immediate operational measures and long-term design changes for the B-737 series airplane to preclude the potential for loss of control from an inadvertent rudder hardover. Once the operational measures and design changes have been developed, the FAA should issue respective airworthiness directives to implement these actions.

B-737 Certification Issues

When the B-737-100 and -200 series airplanes were certificated in 1967, 14 CFR Section 25.695- "Power-boost and power-operated control system," stated the following, in part:

> The failure of mechanical parts (cables, pulleys, piston rods and linkages) and the jamming of power cylinders [such as hydraulic powered actuators] must be considered unless they are extremely remote.[9]

During certification, Boeing provided the FAA a failure analysis of the B-737 rudder control system that analyzed possible malfunctions of the system. In response to several possible failure conditions, including a rudder hardover, the Boeing analysis stated that the airplane's lateral control authority exceeded the rudder control authority and could be used to overcome the

---

[8] Blowdown is the point where aerodynamic forces acting on the rudder equal the hydraulic forces available to move the rudder.

[9] "Extremely remote" was not defined by the FAA in 1967 regulations, and a probability value has not been provided. However, several FAA aircraft certification representatives stated their belief that it is a probability of failure of 1×10^{-6} or less for each flight hour.

effects of a rudder control system failure. In response to the requirements of Section 25.695, Boeing asserted to the FAA certification officials that if a jamming failure immobilized the rudder system, yaw control could be maintained through the use of lateral control. However, based on the results of the flight testing described in the previous section, the Safety Board concludes that the lateral control system may not be able to counteract the effects of a fully deflected rudder at certain airspeeds and flap settings.

The certification basis for the B-737 required that only single failures be considered. Although 14 CFR Section 25.695 was modified in 1970 by amendment 23, which required that multiple and undetected failures be considered, the B-737 airplanes have not been required to meet the revised certification requirements.

Also pertinent to this discussion is 14 CFR Section 25.671, "Control Systems, General,"[10] which states the following, in part:

> (c) The airplane must be shown by analysis, tests, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems), within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable[11] malfunctions must have only minor effects on control system operation and must be capable of being readily counteracted by the pilot.
> (1) Any single failure, excluding jamming (for example, disconnection or failure of mechanical elements, or structural failure of hydraulic components, such as actuators, control spool housing, and valves).
> (2) Any combination of failures not shown to be extremely improbable, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).
> (3) Any jam in a control position normally encountered during takeoff, climb, cruise, normal turns, descent, and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.

An issue of concern to the Safety Board, also noted by the CDR team in its report, is the ambiguity of terminology used in the current regulations. Specifically, the CDR team questioned the interpretation of the term "normally encountered" in 14 CFR Section 25.671 (3).

The CDR team reported that it did "not agree with the rationale that only control positions associated with 'normally encountered' should be considered. There are too many variables (atmospheric conditions, pilot technique, airplane condition (trim requirement), air traffic, etc.) to define 'normally encountered' other than that it may be less than full deflection. The Team's position is that if a control position is possible, it is there for a purpose, and the pilot

[10] Doc. No. 5066, 29 FR 18291, Dec 24, 1964, as amended by Amdt 25-23, 35 FR 5674, Apr. 8, 1970.
[11] "Probable" is defined in FAA Advisory Circular 25.1309-1A as a probability of failure on the order of greater than 1×10^{-5} for each flight hour.

can use that control authority. The only exception to this requirement is the case when full control deflection is only required (provided) to counter another improbable failure or event."[12]

The CDR team's report also states that, "FAR Section 25.671 refers to 'normal flight envelope,' 'exceptional piloting skill and strength,' and 'control position normally encountered' regarding jams in a flight control surface. The CDR Team believes the interpretations that have been applied in the past, regarding amount of flight control input to be considered in showing compliance with the referenced regulations, may not be sufficient."[13]

In response to this observation, the CDR team recommended that the FAA's Transport Airplane Directorate Standards staff develop the following:

> ... national policy and or rule making as necessary and applicable to transport category airplanes that defines 'normal,' with respect to jams. This definition should include consideration of a jam of a control surface at any position up to its full deflection as limited by design, ...[14]

In 1986, the FAA initiated rulemaking activity regarding 14 CFR Section 25.671 that would have updated the regulatory provisions as well as added new requirements for functional isolation and physical separation of vital flight controls. The FAA regulatory activity was suspended after the Aviation Rulemaking Advisory Committee (ARAC) was created in 1992. The ARAC was established to harmonize the various certification regulations, and the FAA project regarding 14 CFR Section 25.671 was assigned to an ARAC working group. A terms of reference (TOR) was submitted to the ARAC in October 1994. The TOR has been approved by the ARAC Executive Committee and is awaiting assignment to a working group. It is currently estimated that tasking of the working groups will occur in April 1997.

FAA representatives stated that they are aware that that the phrase "normally encountered" in 14 CFR Section 25.671 has caused come confusion and concern. The FAA has scheduled a public meeting for December 3, 1996, in Seattle, Washington, to gather information regarding normal control surface positions and control and maneuver margins for the purpose of formulating certification policy concerning this section. The FAA intends that the results of the meeting will be provided to the above-mentioned ARAC as part of the background information for the working group.

The Safety Board is concerned that as it is used in the current regulation, the term "normally encountered" cannot quantitatively be defined and can be subjectively interpreted, which could materially affect the outcome of certification compliance. Any interpretation of "normally encountered" that considers only control deflections less than full deflections may not guarantee adequate safety. Therefore, the Safety Board believes that the FAA should revise 14 CFR section 25.671 to account for the failure or jamming of any flight control surface at its

---

[12] Federal Aviation Administration--B737 Flight Control System Critical Design Review Report, May 3, 1995, p. 4.

[13] Ibid., p. 34.

[14] Ibid., p. 34.

design-limited deflection Following this revision, the FAA should reevaluate all transport-category aircraft and ensure compliance with the revised criteria

Rudder Surface Position Indicator

As previously mentioned, following the United flight 585 accident, there have been heightened sensitivities to perceived flight control problems involving the B-737 series aircraft. As a result, pilot reports of B-737 directional and lateral control system anomalies have increased. None of these events have resulted in the loss of control of an aircraft. Many of these events were perceived by the pilots as rudder-induced upsets.

Detailed examinations of flight recorder data and testing by Boeing and the Safety Board of flight control system components removed from these aircraft have determined that most of the events can be directly attributed to wake vortex encounters, yaw damper coupler failures, yaw damper engage solenoid failures, or aileron inputs induced by autopilot failures In several cases, the flightcrews initially reported the upset events as rudder hardovers or runaways. Both of these terms imply full rudder deflection. In several cases, the flightcrew concluded that a rudder hardover had occurred because "the indicator" showed full deflection The "indicator" to which some flightcrews referred was the yaw damper indicator The yaw damper indicator shows yaw damper operation and is limited to rudder surface travel of either 2° or 3° (depending on B-737 series) to either side of neutral.

Although some newer B-737 aircraft are equipped with a rudder surface position indicator, most B-737s are not On those that are not so equipped, the pilots have no means to determine whether the rudder system is functioning properly On the ground, during the flight controls check, smooth movement of the rudder pedals usually indicates that the rudder system is not jammed, but it does not indicate whether the rudder surface is actually responding properly to the pilot's commands In flight, the rudder pedals will normally provide an indication of the direction of movement of the rudder surface However, the rudder pedals do not move in response to yaw damper-commanded rudder deflections If a yaw damper-commanded deflection of the rudder occurs, there will be no rudder pedal position indication of the direction or magnitude of rudder surface movement if there is no rudder surface position indicator.

The actual rudder surface position in most of the previously noted upsets (including the United flight 585 and USAir flight 427 accidents and the Eastwind incident) was not recorded on the FDR. In all of the reported upsets or yaw events in which FDR information has been available, examination of the data indicates that the rudder deflection was limited to the yaw damper's normal operational limit. Unsubstantiated reports of rudder hardovers indicate that some flightcrews may be unaware of the position of the rudder surface.

On February 22, 1995, the Safety Board issued Safety Recommendations A-95-25 through A-95-27 to the FAA to require the upgrading of FDRs on transport-category airplanes. Safety Recommendation A-95-25, which specifically addressed the B-737, stated the following:

> Require that each Boeing 737 airplane operated under 14 CFR Parts 121 or 125 be equipped, by December 31, 1995, with a flight data recorder system that records, as a minimum, the parameters required by current regulations applicable to that airplane plus the following parameters (recorded at the sampling rates specified in "Proposed Minimum FDR Parameter Requirements for Airplanes in Service"): lateral acceleration, flight control inputs for pitch, roll, and yaw; and primary flight control surface positions for pitch, roll, and yaw

In an April 29, 1996, letter, the Safety Board stated that the FAA's delay in requiring the installation of enhanced FDRs on B-737 was unacceptable. However, the Safety Board provided that it would "consider, as a reasonable course of action, limiting the scope of the urgent recommendation to adding the recorded parameters of rudder pedal and rudder position." In an October 15, 1996, letter, the FAA again refused to take action on Safety Recommendation A-95-25. However, on July 17, 1996, in response to Safety Recommendations A-95-26 and -27, the FAA issued NPRM 96-7, which proposed to require the installation of enhanced FDRs that would record additional parameters FAA staff have estimated that the final rule will be issued by December 1996

The Safety Board notes that installing the sensor to provide rudder position data to an FDR could be used to provide rudder position information in a cockpit display. Therefore, the proposed requirement to install enhanced FDRs would provide the necessary rudder position sensor and greatly facilitate the timely installation of a cockpit indicator system on B-737s that indicates rudder surface position and movement

The Safety Board notes that all of the Airbus series airplanes are equipped with control surface position indicators, including a rudder surface position indicator McDonnell-Douglas provides rudder surface position indicators on the DC-10 and MD-11 series The DC-9 and MD80/90 series have a rudder actuator hydraulic pressure indicator, which indicates whether the rudder hydraulic actuator is powered. However, the DC-9 and MD-80/90 series are certificated for flight with the rudder hydraulic system inoperative

The newer Boeing models (the B-747, B-757, B-767, and B-777) have rudder surface position indicators. A rudder surface position indicator can be ordered as an option on the B-737 series Boeing representatives stated that that it would be possible to retrofit rudder position indicators into older B-737s that are not so equipped but that some engineering design would be required for the installation. The primary requirement would be ensuring that the sensors and wiring are properly incorporated into the existing wiring and electronics package.

The Safety Board concludes that providing a means to ascertain rudder surface position and movement on the B-737 would help flightcrews better assess a control problem and take more timely and appropriate corrective action Additionally, an indication system would provide a means to verify that the rudder was performing properly during the preflight flight control check As the B-737 rudder system has only one rudder panel and one actuator, with no backup systems, a system indicating the rudder position would provide a mechanism to ensure that the rudder is responding correctly to pilot inputs. Therefore, the Safety Board believes that the FAA should require Boeing to develop and install a cockpit indicator system for all new production B-737 airplanes that indicates rudder surface position and movement. For existing B-737 airplanes, when implementing the installation of an enhanced-parameter FDR, the FAA should require the installation of a cockpit indicator system that indicates rudder surface position and movement.

Yaw Damper System Anomalies

As previously mentioned, the Safety Board is aware of numerous reported directional and lateral control system anomalies, the latter also known as yaw upsets, in B-737 series aircraft. Uncommanded yaw excursions within the yaw damper's normal operational limits (2° or 3°) at low airspeeds are generally considered by most flightcrews and operators as nuisance events and do not adversely affect the controllability of an airplane. However, uncommanded yaw damper excursions at higher airspeeds are more violent, because a 2° or 3° deflection can be a significant portion of the available rudder displacement. A yaw damper system failure at high airspeeds can result in cabin occupants being injured.

The Safety Board's investigation of the reported control system anomalies indicates that the yaw damper coupler and yaw damper engage solenoid (a main rudder PCU component) have been frequent causes of yaw disturbances. The Safety Board concludes that the frequency of these occurrences can be decreased by a thorough reevaluation and modification of components of the yaw damper system.

One in-flight upset related to yaw damper system anomalies that resulted in a diversion and precautionary landing occurred on April 11, 1994, when a Continental Airlines B-737-300 experienced an uncommanded simultaneous roll and yaw en route to Tegucigalpa, Honduras. The airplane made a precautionary landing without incident at San Pedro Sula, Honduras.

The FDR data from that flight indicated that the airplane suddenly rolled and yawed to the left at flight level 370 (37,000 feet) shortly after the wings were leveled during an en route turn. The crew applied aileron to oppose the roll and disengaged the autopilot. The yaw damper was not disengaged. The investigation found that the flightcrew had not been trained to disengage the yaw damper if an uncommanded yaw occurred. The flightcrew maintained control of the airplane with no further roll or yaw excursions; however, continuous input to the ailerons was required to maintain level flight.

Analysis of the FDR data indicated that the initial yaw excursion was caused by a full yaw damper deflection, which caused the rudder to move 3° to the left. Subsequent testing of components removed from the airplane identified a yaw damper coupler failure mode that could have resulted in a sudden full yaw damper input command to the rudder.

Testing has demonstrated that a rudder can remain deflected for up to 110 seconds. After 110 seconds, the yaw damper coupler system will automatically recycle, and the rudder will again move to the position commanded by the yaw damper coupler system, which could be any position from neutral to 3°. For example, if a failure in the yaw damper system commanded the rudder to deflect 3°, and the failure was transitory, the yaw damper system would reset after 110 seconds and return to normal operation. If, however, the failure remained, after the 110 seconds the system would continue to detect a full yaw damper command and maintain the 3° rudder input.

Additional laboratory testing of the airplane's yaw damper engage solenoid identified an intermittent failure that also could have caused a sustained full yaw damper command. The cause of the intermittent failure of the yaw damper engage solenoid was determined to be hydraulic fluid contamination of the solenoid's coil assembly. Hydraulic fluid leaked into the solenoid's coil insulation wrapping and provided an electrolytic path that resulted in coil-wire corrosion and deterioration.

After several incidents involving yaw damper hardovers during which hydraulic fluid leaked into the yaw damper solenoid, Boeing developed a yaw damper engage solenoid with encapsulated electrical coils to prevent intrusion of hydraulic fluid; this solenoid is interchangeable with the existing solenoid. One B-737 operator reports a reduced yaw damper system failure rate with the sealed solenoid coil installed. The CDR team report recommended that the FAA review and consider this design change for mandatory incorporation on the B-737.

The CDR team's evaluation of potential B-737 lateral and directional control systems failure conditions found that about 50 percent of the B-737 pilot reports of directional and lateral control system in-flight anomalies were related to the yaw damper coupler. The team recommended that measures be taken to reduce the failure rate.

The Safety Board is also concerned about the yaw damper system failure rate and agrees that incorporation of the encapsulated solenoid and a redesign of the B-737 yaw damper coupler would improve the reliability of the yaw damper system and help prevent in-flight upsets and the potential for injuries. If adopted, docket 96-NM-151-AD in the FAA's recently issued NPRM would require repetitive examinations of the yaw damper coupler and replacement of engage solenoids that do not have the encapsulated electrical coils.

The investigation has found that the B-737 yaw damper coupler is classified, for maintenance purposes, as an "on condition" item; thus, the yaw damper coupler only needs to be inspected and replaced when a failure is detected. In fact, regulations allow a B-737 to be flown on a scheduled passenger flight with the yaw damper system inoperative. However, as previously stated, an in-flight failure of the yaw damper coupler can result in injuries to cabin occupants.

Several airlines have established a service life limit for the B-737 yaw damper coupler to ensure that couplers are removed before failure. These airlines appear to have a lesser frequency of reported uncommanded roll and yaw events since the service life limit for the yaw damper coupler was established.

The Safety Board believes that the FAA should conduct a detailed engineering review of the B-737 yaw damper system, and require Boeing to redesign the yaw damper system, as necessary, to eliminate the potential for sustained uncommanded yaw damper control events. Further, the Safety Board believes that after the yaw damper system is redesigned, the FAA should issue an AD to require the installation of the improved yaw damper system on all B-737 series aircraft.

Main Rudder PCU Yaw Damper Linear Variable Displacement Transducer (LVDT) Replacement

As previously stated, on June 9, 1996, Eastwind Airlines flight 517, a Boeing 737-200, N221US, experienced a roll/yaw upset on approach to land at Richmond Airport, Richmond, Virginia. The flightcrew reported using opposite aileron and rudder input, as well as asymmetric engine power, to right the airplane. The upset subsided when the flightcrew disengaged the airplane's yaw damper system. However, the pilots were uncertain if control was regained as a result of the yaw damper system being disengaged.

Testing and examinations of the main rudder PCU removed from the Eastwind incident airplane indicate that the yaw damper system could move the rudder 1½° to the left and 4½° to the right. The normal limits for this PCU were 3° left and right. Also, the examination of the Eastwind PCU found that the LVDT had been incorrectly set, which caused the yaw damper to operate at less than nominal rudder deflection in one direction and more than nominal rudder deflection in the opposing direction.

The Boeing 737 series airplane's main rudder PCU was designed so that the rudder position transducer, an LVDT, was a line replaceable unit (LRU). This allowed the LVDT to be replaced by airline service mechanics rather than removing the PCU from the airplane for the LVDT to be replaced at an overhaul facility.

The Safety Board's investigation of this incident found that as a result of a previous yaw damper system anomaly, the LVDT on N221US was replaced by airline service mechanics per Boeing maintenance manual instructions (22-11-51A). The replacement procedures in the Boeing maintenance manual do not provide testing to verify that the replacement LVDT functions properly. The Safety Board is concerned that LVDTs are being replaced as LRUs without adequate testing to ensure that the yaw damper system moves the rudder within its appropriate range. Therefore, the Safety Board believes that the FAA should require Boeing and the operating airlines to eliminate the procedure for removal and replacement of the main rudder PCU rudder position transducer from their respective B-737 maintenance manuals unless the manual provides for testing to verify that the replacement transducer performs its intended function.

Main Rudder PCU Service Life Limit

The B-737 main rudder PCU was originally designed with a service life of 12,000 flight hours. At this 12,000 flight hour limit, the PCU was to be removed, inspected, tested, and overhauled. After acceptable service experience was gained, the FAA reclassified the PCU as an "on-condition" component, requiring inspection of the PCU only when a problem is noted.

The Safety Board has not found indications in the PCUs examined of any failures that would have caused a loss of rudder control. However, it is evident that the close tolerances required for proper operation of the PCU require regular inspection and testing to ensure that potential failures can be detected before failure. A failure of the PCU that causes an uncommanded deflection of the rudder can cause serious injury to passengers and crew or loss of control of the airplane. Again, because the B-737 rudder system has only one rudder panel and one actuator, whereas most other transport-category airplanes' rudder systems have two rudder panels with two actuators, or one rudder panel with three actuators, the Safety Board is concerned about the B-737 rudder system's lesser degree of redundancy. If the rudder PCU were to fail, the B-737 rudder system does not have the multiple redundancy features that exist on other, later-designed transport-category airplanes. The availability and reliability of the rudder is dependent on the condition of critical components, the most important of which in the B-737 is the rudder PCU.

The Safety Board notes that most B-737 main rudder PCUs have been recently modified in accordance with AD 94-01-07, which was issued on January 3, 1994. The AD requires modification of the PCU to prevent overtravel of the secondary slide. However, the PCUs are not necessarily overhauled when they are modified. Therefore, a latent failure may not be detected and corrected.

The investigation has determined that the condition of the B-737 main rudder PCU is critical to the safety of flight and notes that currently no internal inspections are required of the PCU until a failure occurs. It would seem evident that all B-737 main rudder PCUs should receive periodic inspections to ensure that a problem is detected before it could endanger a flight. Therefore, the Safety Board believes that the FAA should require Boeing to establish appropriate inspection intervals and a service life-limit for the B-737 main rudder PCU.

Main Rudder PCU Latent Secondary Servo Valve Jamming

The investigations of the previously mentioned accidents and incidents have involved extensive examinations, testing, and a design review of the B-737 main rudder PCU. The PCU contains a redundant control system with a dual-concentric servo valve. A failure of the servo valve can result in degraded performance of the PCU that varies from slow rudder response to uncommanded movement of the rudder. Uncommanded movement of the rudder can occur if both the primary and secondary slides of the dual-concentric servo valve are jammed and cannot be repositioned to a neutral or null position.

While there has never been a documented case of an uncommanded full rudder hardover caused by jamming of the servo valve or failure of the PCU, the Safety Board is aware of five incidents in which rudder control anomalies involved jams of the servo valve slides. Two of the incidents occurred in flight. None of the incidents resulted in damage to the aircraft.

In all single-failure conditions of jamming the primary slide to the secondary slide, the PCU maintains control of the rudder by using the secondary slide to offset the effects of the jam of the primary slide. Although the jamming may cause the rudder to move at a different rate than commanded, it is doubtful that most pilots would notice the change in the rudder rate unless the jam resulted in an offset of the rudder position or sustained rudder movement

A jam of the secondary slide to the servo valve housing also may not be detectable during normal operations because the movement of the secondary slide occurs only when a high-rate rudder command is input. However, even a preflight control check that inputs a high-rate rudder movement to command secondary slide movement may not enable pilots to detect a jammed secondary slide, because pilots may not perceive the difference in rate An undetected or latent jam of either slide increases the likelihood that control of the rudder PCU will be lost if the remaining slide jams.

Because of the low probability of detecting a latent jam of either PCU servo valve slide, the Safety Board believes that the FAA should require Boeing to devise a method to detect a primary or a secondary jammed slide in the B-737 main rudder PCU servo valve and ensure appropriate communication of the information to mechanics and pilots

Main Rudder PCU Servo Valve Chip Shearing Capacity

Aircraft hydraulic servo valves are designed to be able to cut or shear relatively large contaminants that enter the valve The ability of the valve to function when a contaminant enters the valve depends upon both the input force, either from rudder pedals or the yaw damper system, to the valve and the design of the valve, the combination of which defines the valve's chip shearing capacity. The chip shearing capacity of a servo valve can be measured by the valve's ability to operate smoothly and without jamming in the presence of contaminants

The investigation of the USAir flight 427 PCU determined that the input force to the main rudder PCU servo valve was approximately 40 pounds, which is within the tolerances of the PCU design The Safety Board conducted tests of the servo valve's ability to shear contaminants using particles of Teflon, aluminum, steel, and other contaminants The size of the materials used in the test were considerably larger than those that would normally be trapped in the PCU's hydraulic fluid filters. In all but one test, a 40-pound force on the servo valve sheared the contaminant, and the valve did not jam A particle of 52100 steel could not be sheared in the testing at the 40-pound force level. However, the particle left a visible mark on the valve. USAir flight 427's servo valve components exhibited no marks that would indicate that a jam had occurred

The CDR team noted that the Douglas Aircraft Company provides a minimum input force to the hydraulic servo valves of 100 pounds, which provides a significantly higher chip shearing capacity. The CDR team also stated that, "valve-chip shearing forces on this actuator [B-737] seem to be marginal."[15] The team recommended that the FAA's Transport Standards Service develop a national policy for transport-category airplanes requiring the determination of critical hydraulic flight control system and component sensitivity (jam potential and actuator performance) to contamination, requirements for sampling hydraulic fluid, and requirements for actuator components to eliminate or pass (shear) particulate contamination

[15] Ibid., p. 9.

The Safety Board's testing of rudder PCUs during the previously mentioned investigations supports the CDR team's recommendation Therefore, the Safety Board believes that the FAA should evaluate the adequacy of the chip shearing capacity for all sliding spool control valves used in transport-category aircraft flight control systems and take appropriate action to correct any problems identified to preclude potential for actuator jamming, binding, or failure

Standby Rudder Actuator Galling

Galling is a process in which metal is transferred from the surface of one metal component to another It is normally caused by relatively high loads forcing the two surfaces together The examination of the standby rudder actuators from both United flight 585 and USAir flight 427 indicated evidence of galling on the bearing surface of the standby rudder actuator input shaft The area galled on the bearing surface from United flight 585 was considerably larger than that on USAir flight 427

Tests conducted by the Safety Board found that severe galling of the input shaft could result in greater-than-normal movement of the rudder However, the tests indicated that even in the most extreme case of galling it was possible for the pilot to neutralize any adverse effects of galling by pushing the appropriate rudder pedal

In the CDR team's evaluation of the B-737 standby rudder system, galling of the input shaft bearing was identified as an area of concern and found that galling could cause an uncommanded rudder movement The team recommended that appropriate action be taken to correct the galling condition of the standby rudder on the B-737

If adopted, Docket 96-NM-147-AD in the FAA's recently issued NPRM would require repetitive operational tests and inspections of the standby rudder PCU and replacement of the bearing with an improved design within 3 years of the AD's adoption Although the Safety Board agrees with the intent of the FAA's proposed AD, the Board disagrees with allowing 3 years for the installation of the new design bearing The Safety Board is concerned that even though the rudder movement caused by severe galling can be overpowered by pilot action, a sudden rudder deflection can result in injuries to cabin occupants Further, if the pilot does not or cannot correct the problem by using the rudder pedals, large yaw and roll angles might rapidly develop At low altitudes, a pilot might not have sufficient time to regain control of the airplane

The Safety Board notes that Boeing has already developed a standby rudder input shaft bearing design that will either prevent or lessen the potential for galling Additionally, the FAA has estimated that the installation of the new bearing should take only about 3 hours per airplane Therefore, the Safety Board believes that the FAA should require the modification of the input rod bearing on the B-737 series standby rudder actuator to prevent galling and possible discrepant operation of the rudder system by August 1, 1997

Hydraulic Fluid Sampling Program

In support of the USAir flight 427 accident investigation, the Safety Board, with the assistance of the hydraulic fluid manufacturer and the FAA, collected and examined 104 samples of hydraulic fluid from 21 in-service B-737 airplanes. Samples ranged from a National Aerospace Standard (NAS) 1638, "Cleanliness Requirements of Fluids used in Hydraulic Systems," Class 1 (least contaminated) to Class 13 (most contaminated), with the mean for all samples found to be Class 7.5.[16]

Although aircraft component and hydraulic fluid manufacturers provide recommendations for periodic testing of hydraulic fluid contamination to ensure that it meets in-service limits, the FAA does not require routine hydraulic fluid particulate contamination testing or provide a standard for maximum levels of allowable contamination. The CDR team examined the issue of hydraulic fluid contamination and noted that, "the sensitivity of hydraulic components (including actuators and their controlling elements) to chemical or particulate contamination has not been fully established."[17]

The CDR team report noted that the Douglas Aircraft Company has maintenance manual requirements for fluid sampling intervals and a contamination standard of NAS 1638 Class 9. Boeing does not provide recommendations for hydraulic fluid sampling or particulate contamination standards. However, Boeing specifications provide that hydraulic fluid contamination should be no more than NAS 1638 Class 9 when airplanes leave the factory. Boeing service manuals state that the intervals for fluid sampling or replacement/replenishment are to be established by the operator and its hydraulic fluid supplier. Boeing establishes hydraulic fluid property limits in the B-737 aircraft maintenance manual for visual condition, specific gravity, percent water by weight, neutralization, viscosity, organic contamination, and elemental contamination. Boeing also provides guidance for the inspection and replacement of hydraulic system filters, which provides a method to improve the cleanliness of hydraulic fluid.

During the November 1995 public hearing for the USAir flight 427 accident, the Safety Board learned that the FAA had requested that the Society of Automotive Engineers (SAE) evaluate the need for hydraulic fluid contamination standards. The Safety Board supports this effort and hopes that the findings of the SAE committee established to evaluate this need will result in hydraulic fluid contamination standards for aircraft. The Safety Board believes that the FAA should define and implement standards for in-service hydraulic fluid cleanliness and sampling intervals for all transport-category aircraft.

British Airways Boeing 747-436 Upset On Departure From London

On October 7, 1993, a British Airways Boeing 747-436, G-BNLY, experienced an in-flight upset as the airplane climbed through 100 feet above ground level on departure from

[16]NAS 1638 does not define a Class 7.5. Class 7 or 8 would be the accepted standard for the sample. Standard deviation for the sample lot was 1.95.

[17]Federal Aviation Administration--B737 Flight Control System Critical Design Review Report, May 3, 1995, p. 35.

London's Heathrow Airport The aircraft suddenly pitched down from 14° nose up to 8° nose up because of uncommanded full-down travel of the right elevators The flightcrew maintained control of the aircraft and continued the flight The incident was investigated by the Air Accidents Investigation Branch (AAIB/UK) of the United Kingdom and is described in AAIB/UK Aircraft Accident Report 1/95.[18]

Examination of data recorded on the airplane's quick access recorder indicated that the airplane's right elevators moved to near their maximum down deflection (nose-down pitch) limit without a command from the flightcrew. In response, the flightcrew commanded a nose-up pitch, which caused the elevators on the left side to move up, opposite of the right elevators. The airplane suffered no major damage, and there were no injuries on board the airplane.

The AAIB/UK investigation identified the following causal factors:

(*i*) The secondary slide of the servo valve of the inboard elevator Power Control Unit (PCU) was capable of overtravelling to the internal retract stop; with the primary slide moved to the limit imposed by the extend linkage stop, the four chambers of the actuator were all connected to both hydraulic supply and return, the servo valve was in full cross-flow resulting in uncommanded full down travel of the right elevators.
(*ii*) A change to the hydraulic pipework associated with the right inboard elevator Power Control Unit was implemented on the Boeing 747-400 series aircraft without appreciation of the impact that this could have on the performance of the unit and consequently on the performance of the aircraft elevator system, in that it could exploit the vulnerability of the servo valve identified in (i) above

As a result of the investigation, the AAIB/UK recommended that the Safety Board "consider re-issuing safety recommendation A-92-121 to verify that its full intent has been met."

Safety Recommendation A-92-121 was issued as a result of the Safety Board's investigation of a July 16, 1992, B-737-300 incident in which potential design deficiencies in the B-737 main rudder PCU servo valve were identified In a safety recommendation letter dated November 10, 1992, the Board advised the FAA that analysis indicated that the potential for rudder reversal could exist in all B-737 main rudder PCUs. The internal stops of the dual concentric servo valve could allow the secondary slide of some valves to overtravel under some conditions Normally, the primary slide moves about 0.045 inch before the secondary slide moves If the primary slide is pinned or jammed to the secondary slide, control inputs resulting in the normal movement of the primary slide could lead to overtravel of the secondary slide. If the overtravel of the secondary slide is sufficient, hydraulic fluid could be routed through a flow passage located outside the normal valve operating range that could result in piston (and rudder) motion in the direction opposite to the input command.

Safety Recommendation A-92-121 asked the FAA to do the following:

[18]Air Accidents Investigation Branch, "Report on the incident to Boeing 747-436, G-BNLY at London Heathrow Airport on 7 October 1993."

> Conduct a design review of servo valves manufactured by Parker Hannifin having a design similar to the B-737 rudder power control unit servo valve that control essential flight control hydraulic power control units on transport-category airplanes certified by the Federal Aviation Administration to determine that the design is not susceptible to inducing flight control malfunctions or reversals due to overtravel of the servo slides.

On January 19, 1993, the FAA responded that it had completed a design review of the servo valves manufactured by Parker Hannifin on all transport-category airplanes and concluded that the problem existed in the main rudder PCU only on the B-737 model airplanes. On June 10, 1993, based on the FAA's response, the Safety Board classified the safety recommendation "Closed--Acceptable Action."

The AAIB's investigation of the British Airways B-747 incident indicated that the inboard elevator PCU failed because of overtravelling of the servo valve secondary slide to the internal retract stop; the primary slide had moved to the limit of the extend linkage stop. This potential for failure was the basis for the concerns expressed in the Safety Board's safety recommendation letter of November 10, 1992. The Safety Board is concerned that the potential for this failure was not identified during the FAA reviews conducted in response to Safety Recommendation A-92-121. The Boeing 747 elevator PCU and B-737 main rudder PCU are similar in that they are both controlled by a dual concentric servo valve and produced by the same manufacturer.

The AAIB incident report noted Boeing's response when queried about what consideration was given to the Boeing 747-400 inboard elevator PCU in response to the Safety Board's Safety Recommendation A-92-121:

> Parker did an analysis to support the NTSB recommendation. Parker looked at all possible jam positions with pilot limiting linkage stops, specifically with the primary valve jammed at null and determining possible <u>reversals</u>. There were no discrepancies uncovered and therefore no actions taken. The extreme stop condition was not envisioned at the time.

In its report, the AAIB stated that "Boeing now maintain [sic] that the 'extreme stop condition' was recognised [sic] in the mid-1970s'."[19] In its analysis, the AAIB provided the following:

> It is surprising that the extreme stop condition was not reconsidered for the Boeing 747-400 elevator unit as that seems to be the very factor in the Boeing 737 rudder unit which led to the recommendation. However, it is most unlikely that even if secondary travel to the internal retract stop had been considered, that the hydraulic mechanism now known to be a driving force would have been foreseen, given the amount of work required since the incident to discover its existence. Nevertheless, this event does indicate that the widest implications of the recommendation and its comprehensive

[19] Ibid., p. 22.

application to "determine that the design is not susceptible to inducing flight control malfunctions or reversals due to overtravel of the servo slides" was not achieved.

The FAA response to the recommendation that, "The problem was found to exist only in the main rudder power control unit on the Boeing 737 model airplane" would appear to be inaccurate or "the problem" was too tightly defined.[20]

The British Airways B-747 incident and findings related to the B-737 servo valve during earlier Safety Board investigations demonstrate that the potential for failure of these valves may exist in other designs and applications and that these failures were not envisioned during the initial design and subsequent in-service operation. The Safety Board concludes that the earlier recommendation to study only those control valves manufactured by Parker Hannifin should be expanded to include all manufacturers to ensure that others do not contain similar failure modes. Therefore, the Safety Board believes that the FAA should conduct a detailed design review of all dual concentric servo valves that control essential flight control system actuators on transport-category airplanes certificated by the FAA to determine if the design is susceptible to inducing flight control malfunctions and/or reversals due to unexpected improper positioning of the servo slides. If the design is determined to be susceptible, the FAA should mandate appropriate design changes.

Unusual Attitude Recovery Procedures

The United flight 585 and the USAir flight 427 accidents and the Eastwind incident involved sudden, unexpected upsets. As mentioned previously, simulator testing indicates that with a fully deflected rudder and at the configuration and conditions found in the USAir flight 427 accident, a B-737-300 can be controlled using full lateral control if the airspeed remains high enough to provide roll authority. However, recovery would require immediate pilot recognition of the upset event and immediate application of flight control inputs to the full authority of the airplane's lateral control limits.

At the time of the USAir flight 427 accident, neither the USAir B-737 Pilot's Handbook nor the Boeing B-737 Operations Manual contained procedures to address uncommanded yaw or roll. However, the substantial number of in-flight failures of the yaw damper system on B-737 series aircraft prompted Boeing to add to its operational procedures a requirement for B-737 flightcrews to disengage the yaw damper system upon experiencing any unexplained or uncommanded yaw disturbances.

On December 9, 1994, a procedure was added to the B-737 Operations Manual to turn off the yaw damper switch if uncommanded yaw or rudder oscillation occurred in flight. Before this change, flightcrews were to turn off the yaw damper only when the yaw damper light remained illuminated. Although the Safety Board agrees that the modification to the B-737 Operations Manual is an improvement, there is no requirement for turning off the yaw damper switch to be a trained memory item. The Safety Board notes that in several incidents following a yaw damper

[20] Ibid., p. 30.

hardover, flightcrews did not disengage the yaw damper system The flightcrew continued to fly with the yaw damper system engaged and incorrectly diagnosed perceived flight control problems when the correct solution would have been to immediately disengage the yaw damper system Therefore, the Safety Board believes that the FAA should require Boeing, working with other interested parties, to develop procedures that require B-737 flightcrews to disengage the yaw damper in the event of an uncommanded yaw upset as a memorized or learned action. Once the procedures are developed, require operators to implement these procedures

A Boeing publication, Flight Operations Review,[21] dated July 13, 1993, addresses the subject of unwanted roll tendencies, as follows:

> If aileron control is affected, rudder inputs can assist in countering unwanted roll tendencies. The reverse is also true if rudder control is affected
>
> If both aileron and rudder control are affected, the use of asymmetrical engine thrust may aid roll and directional control
>
> When encountering an event of the type described above, the flightcrew's first consideration should be to maintain or regain full control of the airplane and establish an acceptable flight path This may require the use of unusual techniques such as the application of full aileron or rudder . . .

Interviews with FAA personnel and representatives from several airlines indicated that the Flight Operations Review may not be widely distributed among flightcrews Several check pilots and FAA inspectors had never seen the publication and were unaware of its existence

Because of the importance of the information contained in the July 13, 1993, "Flight Operations Review," it would seem prudent to include that information in the B-737 Pilot's Handbook Numerous procedures in the B-737 Pilot's Handbook concern events that occur much less frequently than uncommanded rolls or yaws Most of the events for which procedures have been developed are extremely rare, compared with the relatively more common uncommanded roll or yaw excursions Therefore, the Safety Board believes that the FAA should require Boeing to develop operational procedures for B-737 flightcrews that effectively deal with a sudden uncommanded movement of the rudder to the limit of its travel for any given flight condition in the airplane's operational envelope Once the operational procedures have been developed, the FAA should require B-737 operators to provide this training to their pilots

Training In Unusual Attitude Recognition and Recovery

The Safety Board is aware that several airlines provide flightcrew training programs in unusual attitudes and aircraft upset recovery and that these "Advanced Maneuver Training" or

[21]The Flight Operations Review, "a message to flightcrews from the Boeing Commercial Airplane Group," is described by Boeing as " . . for operators and their flightcrews in order to provide advisory information related to flight operations All information [in the publication] is considered accurate However, it is not intended to replace or supersede information contained in approved operating documentation "

"Selected Event Training" programs have been enthusiastically accepted by flightcrews. Typically, these programs have been integrated into a pilot's initial and recurrent training and little additional simulator or flight time is required for the training.

Over the last 27 years, the Safety Board has issued five safety recommendations that addressed training in the recognition of and recovery from unusual attitudes. Safety Recommendation A-70-21, issued on May 1, 1970, referenced an accident that occurred on November 16, 1968, in which a B-727 lost control in poor weather conditions. The Safety Board recommended additional flightcrew training, whereby pilots would be required to demonstrate, periodically, proficiency in the area of recovery from unusual attitudes. The Safety Board also suggested that a simulator be utilized to provide flightcrew familiarization in the following areas:

A. The various instrument display indications associated with and resulting from encounters with unusual meteorological conditions.
B. The proper flightcrew response to various display indications.
C. Demonstration of and recovery from ensuing unusual attitudes.

On May 21, 1970, the FAA responded:

> Airline training now emphasizes proper use of trim, attitude control and thrust, which is far more effective than the practice of recovery from unusual attitude maneuvers, which was deleted from the pilot proficiency check in 1965. It is inconceivable to require training maneuvers which would place a large jet airplane in a nose high, low airspeed, high angle-of-bank situation.

On August 17, 1972, the Safety Board classified the FAA's response "Closed--Unacceptable Action," as the FAA planned to take no action on this issue.

On March 31, 1971, a Boeing 720B yawed and crashed while the crew was attempting a three-engine missed approach. The Safety Board attributed the probable cause of the accident to a failure of the aircraft's rudder actuator, and the Safety Board expressed concerns regarding the flightcrew's ability to rapidly assess the situation and to effect a recovery. As a result of this accident, the Safety Board issued Safety Recommendation A-72-152, which asked the FAA to require pilots to demonstrate their ability to recover from abnormal regimes of flight and unusual attitudes solely by reference to flight instruments. The use of simulators was recommended for this purpose. The Board noted that if current simulators were not capable of being used for this purpose, they should be modified.

The FAA responded that it did not believe that simulators were capable of simulating certain regimes of flight that go beyond the normal flight envelope of the aircraft. Further, because an aircraft simulator is not required as part of an air carrier training program, the FAA stated that it could not require that a simulator be replaced or modified to simulate regimes of flight outside the flight envelope of the aircraft. Because of the FAA's response, on January 16, 1973, the Safety Board classified this safety recommendation "Closed--Unacceptable Action."

As a result of a July 10, 1991, accident at Birmingham, Alabama, involving a Beech C99, the Safety Board issued Safety Recommendation A-92-20, which asked the FAA to require that recurrent training and proficiency programs for instrument-rated pilots include techniques for recognizing and recovery from unusual attitudes.

The FAA responded that pilots are already required to demonstrate recovery from unusual flight attitudes on the private pilot examination. In addition, the FAA noted that the instrument rating requires a pilot to be proficient in this area; therefore, by the time an individual has the required experience to become part of a flightcrew with a 14 CFR Part 121 or 135 air carrier, the pilot has received extensive training and flight checks for procedures and techniques in recovery from unusual attitudes.

On January 26, 1993, the Safety Board classified the recommendation "Closed--Unacceptable Action." In its response letter to the FAA, the Safety Board stated that it "continues to believe that instrument-rated pilots should receive recurrent training in techniques for recognizing and recovering from unusual attitudes and that proficiency programs should include this same training. The Board believes that requiring this training annually will greatly enhance a pilot's ability to safely recover from an unusual attitude."

Following a December 28, 1991, accident that occurred near Block Island, Rhode Island, the Safety Board issued Safety Recommendation A-93-72, which asked that the FAA consider amending 14 CFR Part 135 to require that commuter air carriers perform certain hazardous training, testing, and checking maneuvers, such as engine-out operations, and recovery from unusual flight attitudes, in approved flight simulators to the maximum extent feasible.

On December 13, 1994, the FAA issued an NPRM concerning new air carrier training requirements. In particular, this NPRM proposed requiring certain 14 CFR Part 135 air carriers to conduct training under 14 CFR Part 121. As this met the intent of the recommendation, the Safety Board classified this recommendation "Closed--Acceptable Action." The Safety Board notes that the FAA has recently completed rulemaking action to ensure that pilots operating under 14 CFR Part 135 receive the same level of training as those operating under 14 CFR Part 121.

The Safety Board has also addressed the subject of crew response to unusual attitudes in previous investigations. The report of the Safety Board's investigation of an accident involving a DC-8-63, near Swanton, Ohio, on February 15, 1992, addressed the subject of airline pilots' reluctance to apply aggressive flight controls. The report stated the following:

> ...basic control manipulations by the first officer during the recovery attempt were in general accordance with accepted procedures in that he attempted to roll the wings level and then began pulling the nose up. If he had been more aggressive with both sets of controls, he might have succeeded. A larger, more rapid aileron input would have leveled the wings faster; and a more aggressive pullout could have been within the operating envelope of the aircraft... Obviously, this situation called for extremely quick and aggressive control inputs.

The report noted that airline pilots are not periodically trained to recover from unusual attitudes as are military pilots or civilian acrobatic pilots.

Most recently, the Safety Board addressed the issue of unusual attitude recovery in its report of the accident involving Simmons Airlines flight 4184, an ATR 72-212, N401AM, at Roselawn, Indiana, on October 31, 1994. The Safety Board's investigation found that, "if the operators had been required to conduct unusual attitude training, the knowledge from this training might have assisted the flightcrew in its recovery efforts...." and that operators' respective training programs might be insufficient to demonstrate the cause for and the recovery from aircraft attitudes that are not considered to be "normal."

As a result of its investigation, the Safety Board issued Safety Recommendation A-96-66, which recommended the following to the FAA:

> Amend the Federal Aviation Regulations to require operators to provide standardized training that adequately addresses the recovery from unusual events, including extreme flight attitudes in large, transport-category airplanes.

The above discussion highlights the Safety Board's longstanding concern about the need for air carrier pilots to receive additional and recurrent training in the recognition of and recovery from unusual attitudes. It is recognized that pilots receive unusual attitude training when obtaining their private pilot and commercial pilot certificates as well as their instrument ratings. However, the ability to recognize and recover from an unusual attitude can be severely diminished after several years and thousands of hours in airline operations with no additional or recurrent unusual attitude training. Additionally, the airplanes in which the pilots received unusual attitude training are most likely dissimilar from the airplanes they regularly operate. Recognition and recovery skills learned in a light general aviation-type airplane are not necessarily transferable to the operation of a swept-wing, heavy commercial jet aircraft.

Even when commercial airline pilots have been trained in swept-wing, heavy commercial aircraft to be more aggressive in the application of flight control inputs during rejected takeoffs, windshear escape, and emergencies, such as the loss of engine power, the reactions to these events do not replicate those needed to properly recover from a severe unusual attitude, and in some cases may be counterproductive or reduce the potential for recovery. Therefore, additional training is necessary to ensure that flightcrews respond quickly, aggressively, and with the correct control inputs if an unusual attitude situation occurs.

The Safety Board notes that many accidents and incidents have involved airplanes that achieved attitude and flightpath angles that were outside the "normal flight envelope." However, although the airplane achieved unusual attitudes or flightpath angles, the angle-of-attack and side slip angle were within the "normal flight regime" of the airplane before the achievement of the more severe attitude and flightpath angles. It is the Safety Board's understanding that most simulators would have the capability to provide positive unusual attitude training to the point of aerodynamic stall regardless of attitude.

The Safety Board remains convinced that unusual attitude training programs would improve the safety of air transport-category aircraft. Therefore, the Safety Board believes that the FAA should require 14 CFR Part 121 and 135 operators to provide training to flightcrews 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.

Because this recommendation expands upon the intent of Safety Recommendation A-96-66, the Safety Board classifies Safety Recommendation A-96-66 "Closed—No Longer Applicable Superseded."

Recommendations

As a result of the investigation of these accidents and incidents, the National Transportation Safety Board recommends the following to the Federal Aviation Administration:

Require the Boeing Commercial Airplane Group, working with other interested parties, to develop immediate operational measures and long-term design changes for the B-737 series airplane to preclude the potential for loss of control from an inadvertent rudder hardover. Once the operational measures and design changes have been developed, issue respective airworthiness directives to implement these actions. (A-96-107)

Revise 14 CFR section 25.671 to account for the failure or jamming of any flight control surface at its design-limited deflection. Following this revision, reevaluate all transport-category aircraft and ensure compliance with the revised criteria. (A-96-108)

Require the Boeing Commercial Airplane Group to develop and install a cockpit indicator system for all new production B-737 airplanes that indicates rudder surface position and movement. For existing B-737 airplanes, when implementing the installation of an enhanced-parameter flight data recorder, require the installation of a cockpit indicator system that indicates rudder surface position and movement. (A-96-109)

Conduct a detailed engineering review of the B-737 yaw damper system, and require the Boeing Commercial Airplane Group to redesign the yaw damper system, as necessary, to eliminate the potential for sustained uncommanded yaw damper control events. After the B-737 yaw damper system is redesigned, issue an airworthiness directive to require the installation of the improved yaw damper system on all B-737 series aircraft. (A-96-110)

Require the Boeing Commercial Airplane Group and the operating airlines to eliminate the procedure for removal and replacement of the main rudder power control unit rudder position transducer from their respective B-737 maintenance manuals unless the manual provides for testing to verify that the replacement transducer performs its intended function (A-96-111)

Require the Boeing Commercial Airplane Group to establish appropriate inspection intervals and a service life-limit for the B-737 main rudder power control unit. (A-96-112)

Require the Boeing Commercial Airplane Group to devise a method to detect a primary or a secondary jammed slide in the B-737 main rudder power control unit servo valve and ensure appropriate communication of the information to mechanics and pilots (A-96-113)

Evaluate the adequacy of the chip shearing capacity for all sliding spool control valves used in transport-category aircraft flight control systems and take appropriate action to correct any problems identified to preclude potential for actuator jamming, binding, or failure. (A-96-114)

Require the modification of the input rod bearing on the B-737 series standby rudder actuator to prevent galling and possible discrepant operation of the rudder system by August 1, 1997 (A-96-115)

Define and implement standards for in-service hydraulic fluid cleanliness and sampling intervals for all transport-category aircraft (A-96-116)

Conduct a detailed design review of all dual concentric servo valves that control essential flight control system actuators on transport-category airplanes certificated by the Federal Aviation Administration to determine if the design is susceptible to inducing flight control malfunctions and/or reversals as a result of unexpected improper positioning of the servo slides If the design is determined to be susceptible, mandate appropriate design changes (A-96-117)

Require the Boeing Commercial Airplane Group, working with other interested parties, to develop procedures that require B-737 flightcrews to disengage the yaw damper in the event of an uncommanded yaw upset as a memorized or learned action. Once the procedures are developed, require operators to implement these procedures. (A-96-118)

Require the Boeing Commercial Airplane Group to develop operational procedures for B-737 flightcrews that effectively deal with a sudden uncommanded movement of the rudder to the limit of its travel for any given flight condition in the airplane's operational envelope. Once the operational procedures have been developed, require B-737 operators to provide this training to their pilots. (A-96-119)

Require 14 CFR Part 121 and 135 operators to provide training to flightcrews 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. (A-96-120)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman