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NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Boeing 737 Directional Upsets
February 1991 through December 1994

National Transportation Safety Board
Washington, D.C. 20594

January 17, 1995

To: The Record
From: Greg Phillips, AS-40
Subject: Boeing 737 series rudder/yaw damper upsets

This memorandum provides a synopsis of events related to reported rudder control difficulties concerning the Boeing 737 series airplanes. As of this date, I am aware of, and following developments concerning the following reported incidents. Each of these incidents is reported chronologically (most recent first) in narrative format. The list will be updated as circumstances warrant. This memo supersedes my previous memo dated June 1, 1994, addressed to Jack Drake.

14. USAir, Boeing 737-300; N583AU
Flight 511, uncommanded rudder input w/left yaw
On approach to Raleigh-Durham, North Carolina
December 20, 1994

This event was reported to the Safety Board by USAir. The flight crew stated that the airplane was flying in clear skies with no turbulence at 8,000 feet and 250 knots. The left autopilot was engaged, throttles were in SPEED mode and VOR/LOC was engaged. The aircraft experienced a very sharp uncommanded rudder input and yawed to the left. The pilot immediately disconnected the autopilot and autothrottles. The aircraft then returned to level flight. The pilot estimated that the event lasted less than two seconds. The aircraft then remained normal and an uneventful landing was made.

The pilot stated that at the time of the upset, his feet were on the rudder pedals. He did not notice any movement of the rudder pedals during the event or immediately afterwards. The pilot estimated that the bank angle was no more than "three or four degrees." USAir maintenance removed and bench tested the yaw damper coupler and autopilot accessory unit. The K-12 relay in the autopilot accessory unit was determined to be inoperative.

After learning of this event, the Safety Board was informed that on November 12, 1994, this same airplane had encountered a strong rudder input while approaching Philadelphia at 5000 feet and 250 knots. The pilot reported to USAir that the rudder pedals moved during the event. The pilot described the event as a yaw with the ball displaced one ball width. The autopilot was disconnected and the airplane returned to normal flight. USAir maintenance replaced the yaw damper coupler.

13. Ansett (ANS), Boeing 737-300; VH-CZF
Uncommanded roll on descent
Melbourne, Australia
September 2, 1994

Boeing Air Safety notified the Safety Board on September 12, 1994, that a Boeing 737-300 operated by Ansett rolled violently and unexpectedly to the right during a post-maintenance test flight. The airplane was on descent with the engines at idle thrust and 300 knots with the autopilot engaged. The airplane suddenly rolled right and the roll mode dropped out. Three units of left rudder trim were required to keep the wings level. There was no spoiler float.

ANS removed the rudder PCU because the unit had been removed from another ANS airplane for the same reason on February 6, 1994. The PCU had 15571 hours and 12332 cycles. The original PCU on VH-CZF was removed for hydraulic leaking on August 27, 1994.

At the time of the February removal, the PCU bench checked good and was installed on the incident airplane on August 27, 1994. During the bench check, the technician noted that when the unit was first hooked up to the test bench and the hydraulic fluid temperature was at about 68 degrees F, the unit jumped to full retract position. As the fluid temperature increased during testing, the anomaly of jumping to full retract subsided. The technician shut the test bench down and let the fluid temperature decrease. When he tried the test again, the fault was repeatable.

Further investigation showed that there was a current flow of 24 ma on the J1 connector circuit. As the unit heated, the current dropped to 0 (as expected). Electrical overhaul found that pin 5 of J3 on the PCU was shorting to pin 4. Pin 5 appeared spilt and damaged, it was possibly improperly crimped. A new contact was installed into the unit and the unit tested good.

12. British Airways (BA), Boeing 737-200, G-BGJI
Vibration thru airframe/rudder jam
London, England
August 31, 1994

The Safety Board was notified of this event by the FAA on October 12, 1994. The UK-CAA reported to the FAA that during trouble shooting prior to departure, when the standby rudder was selected, the rudder traveled full left and jammed. No rudder movement was possible through the rudder pedals. By selecting the standby rudder to OFF, the rudder traveled freely and returned to neutral. this was repeated for both A and B hydraulic systems. Reselecting "STANDBY" recreated the rudder hardover. After the standby rudder actuator was removed and replaced, the airplane acted normally.

The standby actuator was removed and bench tested during which the full left deflection was reproduced. A partial teardown of the actuator revealed that the servo valve was seized due to

corrosion. The bypass valve was also corroded but functional. The input ball of the input shaft was sheared. The input shaft and shaft bearing appeared corroded. Water was present in the actuator. the unit was forwarded to Boeing EQA for additional evaluation.

11. America West (AMW), Boeing 737-200, N145AW
Flight 886, yaw upset during climb/cruise
Phoenix, AZ
May 23, 1994

The Safety Board was notified by the FAA communications center that the airplane on a flight from Phoenix, AZ to San Jose, CA had made a diversion and precautionary landing at Las Vegas, NV. The diversion was made because the crew reported a vibration while climbing through FL260 to FL310. They then reported an "uncommanded rudder kick." The crew applied appropriate flight control inputs to maintain controlled flight and began to slow the airplane. They then reported a "shudder". The autopilot was disengaged with no effect. The yaw damper was not disengaged. After landing and deplaning of passengers, America West mechanics performed troubleshooting procedures. According to AMW, the yaw damper system BITE check failed, they did not specifically advise Boeing which tests failed. The airplane was subsequently ferried to Phoenix for maintenance.

At Phoenix, the flight data recorder, autopilot accessory unit, and autopilot switching unit were replaced. The yaw damper system failed BITE test on the retest. The yaw damper coupler and main rudder power control unit (PCU) were replaced with no problem resolution. The yaw damper overhead panel switch (P5-3) was replaced along with a second yaw damper coupler. The airplane then passed system checks and was released for service.

The main rudder PCU was sent to Aerocontrols in Seattle, WA for functional test. No anomalies were noted during normal receiving tests or after packing the solenoid valve and transfer valve in dry ice to simulate a cold soak condition. The yaw damper couplers were tested at Honeywell and completed bench functional and temperature cycling tests with no anomalies.

A written crew statement has been requested from America West. Tabular data from the six parameter flight data recorder was received on June 1, 1994.

America West maintenance records indicate (at the time of this reported incident) that seven (7) yaw damper couplers have been removed from their fleet of Boeing 737's for failures. Those records indicate that post-removal examinations indicate that the reasons for failure were undetermined on 5 of the couplers. The other 2 had failed rate gyro's.

10. Continental Airlines (CAL), Boeing 737-300, N17344
Flight 1057, yaw upset during cruise
Flight diversion to San Pedro Sula, Honduras
April 11, 1994

The Safety Board was notified by Continental Airlines that during cruise at FL370, after departure from Tegucigalpa, Honduras, the airplane experienced a uncommanded simultaneous roll and yaw. The flight crew responded with appropriate aileron input to counteract the roll. The crew reported control wheel forces were high following the roll/yaw excursion. The airplane made a precautionary landing without incident at San Pedro Sula, Honduras.

The event occurred shortly after the airplane completed an on-course turn and on to a heading of 167-168 degrees. The airplane had a 3.5 degree airplane nose up pitch trim and was wings level at an airspeed of approximately 242 knots. The airplane suddenly rolled and yawed to the left. The crew responded by applying aileron to oppose the induced roll and disengaging the autopilot. The yaw damper was not disengaged. Control of the airplane was maintained with no further roll or yaw excursions. A banging noise was reported by the crew at the time of the upset. The crew (reportedly) maintained extra airspeed for the approach and landed at a higher than normal touchdown speed. The event was reported to the NASA Aviation Safety Reporting System (ASRS) as accession number 268462.

After landing, attempts to trouble-shoot the system did not duplicate any failure of the flight control systems. The main rudder PCU, yaw damper coupler, flight control computers, and auto-pilot mode control panel were removed for additional examination. There were no significant faults found with any of the components removed other than a higher than nominal output voltage on the rate gyro of the yaw damper coupler. A nominal reading of 0 to 1.5 millivolts is required. The unit was measured at 15.4 millivolts. The solenoid valve on the main rudder PCU was found to be intermittently open. Testing of the main rudder PCU, coupler and engage solenoid was conducted at Parker and Boeing facilities.

Boeing analysis of flight data recorder information indicates that a yaw damper hardover most likely caused the initial yaw excursion. They stated that at an altitude of 37000 feet and an indicated airspeed of 241 knots, the airplane rolled to the left approximately nine degrees. Using the simulator, the roll and heading experienced during the event was duplicated. They also stated that preliminary analysis shows that the event was consistent with a 2.5 degree sustained rudder input which equals the yaw damper authority at the given flight condition.

Boeing testing of the yaw damper engage solenoid valve confirmed an intermittent open resistance condition. Additional testing determined that the offset voltage was at the high end of the allowable tolerance. The intermittent open condition in the solenoid could allow the offset voltage from the PCU to buildup over time within the yaw damper coupler and result in an extended yaw

damper hardover command of 3 degrees rudder. (Note: a PCU with a lower offset voltage could still buildup over time, however, it will take longer to build up and result in a yaw damper hardover signal. Boeing confirmed this condition by laboratory testing on another PCU with a lower offset voltage.) Once the solenoid closes to its normal in-flight position, the yaw damper hardover signal will command the rudder PCU to command up to 3 degrees of rudder deflection. The time that the rudder is deflected is dependent on the offset voltage buildup. The longest the rudder can be deflected on B-737 airplanes is approximately 110 seconds. The offset was always trailing edge left. The rudder deflection can be a one-time occurrence or spread over several intervals, depending on whether the solenoid closes once or several times.

9. America West (AMW), Boeing 737-300, N313AW
Uncommanded rudder deflection during descent
Las Vegas, Nevada (LNV)
Late March 1994

This event was reported to the Safety Board by Boeing. AMW reported an uncommanded left rudder during descent with the autopilot OFF. No other abnormal indications were noted. The airplane landed at LNV without further incident. Maintenance advised that the yaw damper coupler was replaced. A Built-in-Test-Equipment (BITE) test following replacement resulted in failure of tests 1, 3, and 4. The airplane was released with the yaw damper system inoperative per the airplane's approved Minimum Equipment list (MEL). The main rudder PCU was replaced and shipped to Aerocontrols in Seattle, WA for testing.

Testing of the PCU revealed that the solenoid valve had failed to the hard open position. The solenoid valve was replaced and all remaining tests on the PCU provided normal results. Disassembly of the solenoid valve revealed that the wiring was intact and an open circuit was indicated within the solenoid coil.

Boeing was unable to conclusively determine that the uncommanded rudder resulted from the discrepant solenoid, however, results of the BITE test performed during AMW troubleshooting are consistent with the solenoid discrepancy. The faulty solenoid operation could cause uncommanded rudder movements to the limits of the yaw damper authority (3 degrees).

8. Philippine Airlines (PAL), Boeing 737-300, RP-C-4006
Flight 577, Aborted takeoff
Manila, Philippines
November 2, 1993

The Safety Board was notified by Boeing Air Safety on November 4, 1993, that the airplane aborted it's takeoff attempt. The pilot reported that on takeoff at 80 knots, the airplane:

> Suddenly swerved to the left and could not be controlled by the rudder. I observed that the rudder pedal was deflected to the left and could not be centered. I used the steering tiller to maintain directional control. During taxi I tried to continuously exercise the rudder pedals and normal control was regained.

A Boeing customer service representative in Manila reported that all engine parameters were normal and that the two nose gear tires were worn excessively during the incident.

On November 4, 1993, Boeing flight controls engineering requested additional information from the pilot and PAL maintenance. Requests were made for information concerning date of last rudder system maintenance, were the pilot's inputs to the rudder pedals quick? Did the pilot notice any binding? PAL maintenance was asked to verify the standby rudder PCU input force required and check the safety wire on the input bearing. PAL provided tabular FDR data of the event to Boeing.

PAL maintenance removed the main rudder PCU (Parker S/N 1740, P/N 65-44861-9) and was advised to change the trim control switch as well as check the standby PCU for binding, and the feel and centering unit cam for wear. The removed PCU was shipped to Parker for test/overhaul. No anomalies were noted during top assembly testing. Removal and examination of the dual servo valve disclosed no evidence of misalignment between internal summing levers and the valve external stops. Testing of the valve revealed that the secondary slide overtravel condition could not be duplicated when the valve external stops were included. When only the valve internal stops were used, a partial pressure reversal was obtained in the valve retract direction only, there was no pressure reversal in the valve extend direction. (Valve retract equates to PCU extend and left rudder). A reversal in this orientation would produce a right rudder condition (PAL reported left rudder). Based on the above information, Boeing and Parker determined that the rudder PCU could not have caused the reported anomaly.

The standby rudder PCU from this airplane was shipped to the supplier, Dowty. Dowty reported to Boeing that the PCU input bearing lockwire was intact and that the bearing was tight in the PCU manifold. No evidence of galling on the input shaft or bearing was reported. Dowty reported that slight input linkage friction was found. The force was characterized as light and unlikely a factor in rudder system feedback. The friction was determined to be the result of incorrect shimming of the

main control valve during overhaul or manufacture. The unit had been previously serviced by a vendor other than Dowty.

7. Southwest Airlines, Boeing 737-200, N129SW
Flight 1003, Uncommanded rudder movement
Descending near Oklahoma City, OK (OKC)
August 22, 1993

While descending through FL290, the pilot reported that the airplane experienced a "rudder hardover." He reported that the airplane first yawed right then left. The autopilot and yaw damper were disengaged and control was regained. The airplane continued to OKC and made an uneventful landing. A flight attendant received minor injuries to her wrist during the event. The FDR was removed from the airplane after the incident, but a readout by the FDR manufacturer indicated that more than 25 hours had elapsed since the event and the incident was not recorded.

Southwest reported that prior to the event, on August 21, 1993, the main rudder PCU was removed from the incident aircraft because of fluid leakage and was replaced with PCU S/N 1090A. On the morning of August 22, 1993, during preflight, the originating crew observed the rudder moving slightly from side to side with the electric hydraulic pumps on. The aircraft was returned to maintenance and PCU S/N 1090A was removed and PCU S/N 1774A was installed. The aircraft was dispatched and on the first flight after dispatch the incident occurred.

After the incident, a Southwest Airlines mechanic was dispatched to OKC where he determined that the yaw damper was inoperative. The yaw damper failed the BITE check. The rudder PCU solenoid valve was replaced. The yaw damper was deferred in accordance with the MEL and the airplane was returned to service. After the aircraft returned to Dallas, the rudder PCU and yaw damper coupler was replaced in an effort to resolve the problem. The system passed the BITE check and the airplane was returned to service with no further reported problems.

The rudder PCU removed from this airplane was tested at Parker as received (replaced solenoid valve). The unit passed all tests. The solenoid valve removed from this PCU was also shipped to Parker and tested with no anomalies found except that the solenoid engage voltage was one volt higher than the maximum allowed. Boeing and Parker stated that they did not believe that this condition contributed to the reported airplane anomaly.

The yaw damper coupler removed from this airplane was forwarded to Honeywell for testing. Honeywell later advised of discrepant rate gyro operation within this unit. Boeing characterized this finding as the most likely the cause of this upset event.

A review of the maintenance history of PCU's 1774A and 1090A, indicated that 1774A had been repaired by Parker once before for the same yaw damper failure as noted during this incident.

PCU 1090A had been "overhauled and modified" by Aero Controls prior to installation on the incident airplane.

6. Air France, Boeing 737-300, F-GHVM
Flight 8725, Violent yaw while descending
Paris (Orly), France
June 14, 1993

This upset was reported to the Safety Board by the civil aviation attaché to the French embassy in Washington, DC, on September 12, 1994. The incident was reported to the BEA-France on June 28, 1993. All information concerning this event was provided by an English translation (ref 403/CT/94) of a French Bureau Enquetes-Accidents (BEA) report number 0500 IGACEM/BEA/O dated September 2, 1994.

On June 14, 1993, Air France aircraft F-GHVM, experienced a violent yaw movement while it was descending into Orly airport with the autopilot ON, speed 290 knots, and the engines throttled back. The sky was clear, there was no turbulence. The crew reported that the aileron control wheels "took a vertical position" (Boeing notes that this is physically impossible) and the autopilot switched into control wheel steering (CWS) mode. There were no other warnings. The rudder pedals did not move. The autopilot was disengaged while the crew held the control wheel in position. The crew noted that the yaw damper indicator was against the right stop. The yaw damper was switched OFF and the yaw damper indicator recentered (normal position). Two passengers were transported to the Orly Sud medical center for treatment of injuries sustained during the event.

Examination of the FDR data indicated that while descending through 21,200 feet, the rudder moved from a position of -1.4 degrees to 2.1 degrees, the n returned to -2.1 degrees and then to 1,8 degrees. The 1.8 degree position was held until the yaw damper was turned OFF. The autopilot countered the yaw with an aileron input of 7 degrees left until it was disconnected 10 seconds after the yaw oscillations.

The crew responded to the yaw excursion by turning the yaw damper OFF. There was no checklist or operations manual procedure that instructed the crew to turn the yaw damper OFF. As a result of this event Air France has elected to have their flight crews turn the yaw damper OFF if they experience an uncommanded yaw excursion. A review of the maintenance history for F-GHVM indicated that the airplane had experienced four previous uncommanded yaw excursions. In each case no fault could be found with the coupler (it passed BITE checks each time). On January 7, 1993, the write-up read "slight jerks climbing and cruising due to the yaw damper." On May 1, 1993, the write-up read "yaw jerks while cruising." On May 3, 1993, the write-up read yaw jerks while cruising confirmed." On May 5, 1993, the write-up read "jerks confirmed while cruising." The yaw damper coupler was replaced on May 4, 1993. During a May 5, 1993 inspection of the coupler a fault was found in the gyro.

On the day of the incident, the yaw damper computer (coupler) was removed and replaced, three days later, the main rudder PCU transfer valve was replaced. Four days after the incident, the main rudder PCU was replaced. On removal, the coupler BITE checked OK. Examination of the transfer valve found that the valve failed electrically because of contamination of the valve by hydraulic fluid. Maintenance records indicated that the transfer valve was the same valve installed at airplane delivery 9000 hours previous. No maintenance had been performed on the transfer valve. Additional testing of the yaw damper coupler found no faults. The rudder PCU ball joint was found with the Teflon liner missing. The coupler was reinstalled on Air France aircraft F-GFUA on July 30, 1993.

On August 6, 1993, F-GFUA experienced a series of yaw kicks prior to this on the airplane. The pilot reported that while climbing near 6,000 feet, "yaw wobbles were felt", the yaw damper switch was selected OFF. On August 24, 1993, F-GFUA was cruising at FL350 with the autopilot engaged. The airplane experienced a yaw upset when the inoperative yaw damper was switched from OFF to ON. This resulted in the breaking of a door of a rack and an arm rest in the passenger cabin. The yaw damper was switched OFF and the airplane stabilized. Evaluation of the airplane's quick access recorder (QAR) indicated that the lateral acceleration of the event was from 0.407 g right to 0.371 g left. The rudder moved from 4.9 degrees right to 7.4 degrees left (Note-these values exceed the yaw damper's 3 degree limit, the QAR data conversion was questioned since the BEA report states that on a previous flight the values were determined to be 1/3 "too important"). The Safety Board is working to resolve the differences.

Additional examination of the yaw damper coupler at the Honeywell avionics workshop revealed that not until after two weeks of continuous temperature cycling, the fault reappeared. The fault was isolated to the A1 CCA p/n 4031945-904. Further fault finding identified A1U5 as being the root cause of the problem. Pin 3 of this Op-Amp would intermittently rise to around 4 volts by means of an internal source, causing the output at pin 6 to go hardover. Once the failure was identified, the failure was repeatable by inducing the failure of the device with localized heating and cooling. The A1U5 was replaced. Technicians confirmed the failure of A1U5 as the source of intermittent rudder kicks because the valve amp output would go hardover. Additional examinations of the coupler found a noisy rate gyro that intermittently ran slowly and a power interlock failure. Honeywell technicians deemed both of these failures as incidental and not directly related to the A1U5 failure.

5. Air New Zealand, Boeing 737-200, ZK-NAR
Flight 554, uncommanded rudder movement
Descending Auckland, New Zealand
April 16, 1993

The Safety Board became aware of this event on or about April 22, 1993, after a ALPA representative from Air New Zealand contacted our LA regional Office. This contact supplied a copy of the copilot's incident report. On May 11, 1993, Ron Schleede advised Ron Chippindale of the AAIB/New Zealand of the incident and asked that I be contacted with any further information. On

May 26, 1993, Mike Baker of the New Zealand CAA sent me a fax message that said that Ron Schleede's message to Ron Chippindale had been passed to him for response.

His response indicated that "so far nothing of significance has been identified as a cause for the uncommanded deflection." A small amount of Teflon material and corrosion deposits were found. Fluid sample test results were acceptable.

The airplane was descending from FL 350 because of turbulence when at FL 330 a smooth uncommanded rudder input occurred (with rudder pedal feedback). The autopilot corrected for the input by adding approximately 8 units of opposing aileron. The rudder then abruptly returned to neutral. The crew reported that they did not touch the rudder pedals. The uncommanded movements continued randomly left and right every two to three minutes while in cruise.

The crew then elected to select a number of different cockpit switch variations to troubleshoot the problem. The yaw damp was turned OFF and ON. The System A and B Flight Control Switches were cycled OFF and ON, and then to Standby Rudder. The uncommanded inputs continued but at greater frequency during descent regardless of switch positioning with the "possible" exception of when A and B Flight Control Switches were both switched to standby (manual reversion). The pilot and copilot disagreed on uncommanded rudder movement during manual reversion.

The crew set up the approach for landing with A system on standby and B system operating normally. Up to 16 units of aileron were required to maintain wings level just before touchdown. During landing a "large" left rudder offset was experienced which could not be neutralized by the copilot. The rudder gradually returned to normal as the airplane slowed on rollout after landing. The crew stated that they did not feel that the rudder position agreed with the rudder pedal position since the aircraft tracked OK and did not require excessive aileron to counter the rudder. The nose steering was effective and the nose wheel did not seem to be deflected. At all times, rudder travel was indicated by the airplane's yaw and roll with pedal movement. The crew had flown 5 sectors in the airplane and the captain felt that rudder was "a little stiff" earlier. During the problem flight, both crew felt that the rudder was stiffer than normal.

The airplane was ground tested on the evening of April 16, 1993. The anomaly could not be duplicated. The PCU was removed (S/N 792). On April 17, 1993, a test flight was conducted with no problems noted. After the test flight, the standby rudder PCU and yaw damper coupler were replaced, and all mechanical systems were checked and found to be OK. On April 19, 1993, the yaw damper coupler tested OK with the rate gyro "out of limits". The standby and main rudder PCU's tested OK at normal temperatures without loading. When the standby PCU was tested at a cooler temperature and 3000 psi hydraulic pressure, the input arm required up to 4.5 pounds force to move. (Note: Normal force is approximately 0.5 pounds force).

On September 15, 1993, I received a copy of an Air New Zealand report on the incident. The report concluded that:

No proven explanation exists for these events. The aircraft has not experienced any further uncommanded rudder problems. A possible explanation exists for the small rudder deflections but there is no explanation for the large pedal deflection with apparently small rudder deflection on touchdown The standby rudder power unit may have been the cause. Maintenance requirements for standby units will be revised to introduce a hard time inspection.

4. United Airlines, Boeing 737-300 N309UA
Flight 750, rudder movement binding on preflight check
Seattle, WA
January 4, 1993

Reported January 8, 1993, by the United Airlines flight safety office. During taxi-out, the flight controls check was accomplished. During the rudder check on a second run through, the right rudder appeared to be encountering a "hydraulic block/binding". Rechecks found the same result. The airplane returned to the gate. At the gate the results were duplicated. The rudder operation was OK on the first test and failed the second test. The yaw damper was turned off and the failure reappeared. When checked on standby rudder, the system checked OK.

The main rudder PCU was removed from the airplane and shipped to Parker for examination and testing. During testing, the PCU exhibited reduced rates, complete stalls and reversals while being commanded in the retract direction (right rudder), confirming the pilot reported hydraulic lock.

The dual servo valve was removed from the PCU and installed on a servo test fixture. Testing revealed that the valve as a component was incapable of a pressure reversal when properly assembled. Testing conducted with two times the normal applied input force applied to the secondary slide did not cause a reversal. The retaining nut, which was removed and reinstalled for the servo test, was backed off approximately 60 degrees and the valve was retested. On this test, the cylinder pressure reversed to approximately 1200 psi differential. Discussions with the Parker technician indicated that this nut appeared loose when the unit was first disassembled. It was concluded by the group that this nut was backed off when the unit was received at Parker.

As a result of this investigation, Boeing and Parker modified the spring guide which locks this nut in place to provide better engagement for positive retention. Also, the installation procedure for the nut was revised to prevent backing the nut off during the installation process. To further insure that the valve is correctly installed on the PCU and that pressure reversal is not possible, a test was added to the Parker Acceptance Testing Procedure (ATP) and the Boeing Overhaul Manual. This new procedure utilizes special test equipment which attaches to the secondary slide of the dual servo valve (while installed on the PCU) and strokes the slide within the internal limits of the valve.

3. **USAir, Boeing 737-300, N528AU**
Rudder movement binding on post-flight check
San Diego, CA
December 14, 1992

The Board learned of this incident through ALPA engineering on February 12, 1993. This information was reported by Tom Nicastro, USAir airframe engineer to Walter Winkler, Manager Systems engineering on January 12, 1993, in memo 405TCN-93-004.

The pilot log book reported that "after landing, left rudder could only be depressed about half way to normal max position. Right rudder and nose wheel steering were normal. At the gate we applied heavy pressure to the rudder and it appeared to break loose and then operated in a normal manner."

The main rudder PCU (S/N 1347A) was removed on January 28, 1993 and examined at Parker on January 27, 1993. USAir, Parker, and Boeing personnel were in attendance. A hydraulic fluid sample was taken from the PCU prior to the testing. The fluid tests were acceptable by all Boeing and Parker standards. A pre-teardown functional test of the PCU was normal with no anomalies noted.

All yaw damper functional tests were normal. Velocity checks of the actuation rate were normal and the actuator moved smoothly with no binding. The unit failed the maximum allowable external drip leakage test for piston end and center gland seals. The leakage had no effect on the operation of the PCU. The unit also failed the insulation resistance test (megger) for the condition of the electrical wiring. The electrical test failure was determined to be a defective yaw damper servo valve. The defective valve had no effect on the yaw damper operation.

The unit was then disassembled. The servo valve nut was found properly torqued to 170 inch-pounds. All internal parts appeared to be in good condition. The actuator rod piston seals were found badly worn which caused the external leakage. The servo valve was disassembled and inspected and found to meet Parker specifications. the servo valve was then reassembled and flow tested. The valve performed within all Parker test parameters. A secondary spool overstroke test was performed with a pinned primary slide. This test indicated that reversal of fluid porting did occur with the servo valve when the secondary slide contacted the internal stops. An examination of the external stops indicated that the external stops prevented the slide from contacting the internal stops.

USAir engineering concluded that the binding experienced by the crew on December 14, 1992, was not caused by the main rudder PCU. They went on to say that "whatever was causing the rudder bind apparently broke free, and points to a mechanical problem within the linkage from the rudder pedals to the rudder PCU, not a defective rudder PCU." They also recommended that further trouble shooting take place on the incident airplane including a check of the standby rudder components. Any

further log book write up of rudder lock up, binding, restriction, or limited travel is to be reported to USAir maintenance control prior to further flight.

In early March 1993, USAir reported to Boeing that the standby rudder PCU input bearing lockwire was discovered broken. USAir maintenance was asked to check the input shaft bearing to see if it was loose. In the process of checking the torque of this bearing, it was loosened. No breakout torque was specified, but USAir indicated that the nut was tight. The PCU was shipped to Boeing for examination.

As received from USAir, the input crank force requirements were measured both at ambient temperature and cold soaked to -40 degrees F. In all cases, the input force required was less than 0.5 pounds. Upon disassembly of the input shaft/bearing, filmy deposits determined to be PTFE were present on both the pressure and ambient sides of the input shaft seal (similar to that found on the ANZ standby PCU). Minor galling was noted on the input shaft and on the bearing inner diameter. From the information available, Boeing was unable to determine the cause of the fractured lockwire.

2. **United Airlines, Boeing 737-300**
Abnormal rudder control binding during taxi tests
Chicago, IL (ORD)
July 16, 1992

A United Airlines Captain (known as Mack Moore) discovered that the airplane's rudder pedal stopped at about 25 percent left pedal travel during a preflight flight controls check while taxiing to takeoff from O'Hare airport. The airplane was returned to the gate and the rudder PCU was removed. The Captain reported that he had moved the rudder pedals more rapidly than he normally would have moved them during a preflight rudder control check; about the same rate that he might have used during engine out V_1 training.

The PCU was subsequently examined and tested at the UAL facilities in San Francisco, California, and at Parker Hannifin, Irvine, California. During the subsequent testing of the rudder PCU, anomalous actions were observed when the input crank was held against the PCU body stops and the yaw damper piston was in the extend position. The results ranged from sluggish movement of the actuator piston to a full reversal in the direction of piston travel opposite to the direction being commanded. High internal fluid leakage was also noted.

The capability of the PCU to produce force to move the rudder against aerodynamic loads was not measured. The interaction of the yaw damper and the observed PCU operation is not fully understood. In addition, it is unknown whether the yaw damper was commanding rudder movement at the time that the captain performed the rudder control check. Tapping on the dual servo valve body or actuator summing levers prompted the PCU to return to normal operation. Releasing the force on the input crank also returned the PCU to normal operation.

The servo valve is a modular unit that consists of two concentric slides. The primary slide moves within the secondary slide which, in turn, moves within the valve housing. The two slides are moved by summing levers which add the motion from the yaw damper and input crank. Motion of the input crank is controlled by rudder pedal deflection and feedback from motion of the rudder. When rudder motion is commanded, the input crank will move the servo valve slides to connect hydraulic pressure and return circuits from systems A and B to the appropriate sides of the tandem actuator pistons to extend or retract the piston rod. The initial command signal is nulled by a mechanical feedback loop as the rudder reaches the commanded deflection.

An examination of the servo valve components and analysis by Boeing and Parker showed that the anomalous operation of the PCU was caused by aberrant movement of the servo valve slides. During normal operation, the primary slide moves about 0.045 inch relative to the secondary slide. Further movement of the input crank produces simultaneous movement of both slides for another 0.063 inch relative to the housing. In testing the subject PCU, it was originally believed that initial movement of the primary slide caused simultaneous movement of the secondary slide as if the two slides were bound together. This would have resulted in an overtravel of the secondary slide relative to the valve housing. During tests, the overtravel of the secondary slide resulted in unintended and abnormal porting of hydraulic fluid between the pressure, return, and cylinder ports. The initial effect was a high leakage from pressure to return with a reduction of the differential pressure at the cylinder ports for both the A and B systems. However, in the subject PCU, and potentially in others depending on tolerances, the total travel of the secondary slide before contacting a mechanical stop in the valve resulted in a partial or full (3,000 psi) pressure differential across the actuator pistons that was opposite to the direction of the commanded signal. Thus, a pilot desiring left rudder could conceivably end up with a right rudder movement. This condition could only occur if the rudder pedals were moved rapidly to command a maximum rate of rudder travel or if the pedal was, fully depressed to command full deflection of the rudder.

During subsequent testing, it was determined that the overtravel of the secondary slide was not a result of binding, but rather a result of a failure of the secondary summing lever to make contact with its respective stop. The failure was attributed to a manufacturing out-of-tolerance condition which permitted the secondary summing lever to miss the external stop.

1. United Airlines, Boeing 737-291, N999UA
Abnormal in-flight rudder movement
Locations unverified
February 25 & 27, 1991

On February 25, 1991, a flightcrew reported: "On departure got an abnormal input to rudder that went away. Pulled yaw damper circuit breaker." The corrective action was signed off as: "replaced yaw damper coupler and tested per maintenance manual." Interviews with the flightcrew of that flight indicated that, at the time of the event, the airplane was between 10,000 feet and 12,000 feet at an indicated airspeed of 280 knots, in smooth air with the landing gear and flaps up. The first officer

was flying the airplane with the autopilot OFF. The flight had just leveled off, and the first officer was in the process of retarding the power levers to the cruise setting when there was an uncommanded yaw. He estimated that the yaw was to the right 5 to 10 degrees. In the time that it took him to close the throttles, everything returned to normal. The yaw damper was turned OFF and its circuit breaker was pulled before landing.

On February 27, 1991, a writeup by the flightcrew stated "yaw damper abruptly moves rudder occasionally for no apparent reason on "B" actuators. Problem most likely in yaw damper coupler..unintended rudder input on climbout at FL 250. A/P not in use, turned yaw damper switch OFF and pulled circuit breaker. Two inputs, one rather large deflection..." The corrective action was signed off as: "Replaced rudder transfer valve and the system checks OK." Additional interviews with the flightcrew revealed that the first officer was flying the airplane and indicated that he believed that his feet were on the rudder pedals at the time of the event. While climbing through 10,000 feet, he said that he experienced several rapid "jerks" that he could not identify. The flight encountered light turbulence at the time. While continuing the climb between 25,000 and 28,000 feet, he said he felt a significant right rudder input which lasted between 5 and 10 seconds.

The airplane noted in these events was destroyed in an accident at Colorado Springs, Colorado on March 3, 1991. The cause of the accident could not be determined. The accident investigation centered on severe weather at the airport at the time of the accident and mechanical failure of the airplane's flight control systems. Post accident examinations of maintenance records and components from this airplane indicated that the yaw damper coupler removed from the airplane after the February 25 event passed all functional tests. The transfer valve removed from the main rudder PCU after the February 27 event also passed all functional tests. Examination of the main rudder PCU installed on the airplane at the time of the accident indicated that the unit had an intermittent yaw damper engage solenoid. Loose wires were found going to the solenoid. The airplane's standby rudder actuator was found with a galled input shaft. The bearing nut that is adjacent to the input shaft was found rotated out of its normal position after the accident. The safety wire attached to the bearing nut shaft was found broken.