National Transportation Safety Board
Aviation Incident Final Report

Location:	RICHMOND, VA	**Incident Number:**	DCA96IA061
Date & Time:	06/09/1996, 2200 EDT	**Registration:**	N221US
Aircraft:	Boeing B-737-201	**Aircraft Damage:**	None
Defining Event:		**Injuries:**	53 None
Flight Conducted Under:	Part 121: Air Carrier - Scheduled		

Analysis

The Boeing 737-200 experienced a yaw/roll upset while operating at an airspeed of about 250 knots and an altitude of about 4,000 feet msl in visual flight rules (VFR) conditions. The pilots were able to regain control of the airplane and land at the destination airport without further incident. As a result of previous Boeing 737 rudder anomalies, including the fatal accident involving USAir flight 427, a Boeing 737-300, which entered an uncontrolled descent and impacted terrain near Aliquippa, Pennsylvania, on September 8, 1994, Safety Board investigators initiated an investigation into this incident. Investigators conducted detailed examinations of pertinent rudder control components, reviewed flight test data, performed a computer simulation, and completed an analysis of human performance data. As a result, the Safety Board concluded that the rudder reversed, moving to its right blowdown limit when the captain commanded left rudder, consistent with a jam of the main rudder power control unit servo valve secondary slide to the servo valve housing offset from its neutral position and overtravel of the primary slide. The complete report of this incident investigation, including all analyses, is contained in the final report of the USAir flight 427 investigation which can be found on the NTSB web site at the following link:
http://www.ntsb.gov/publictn/1999/AAR9901.pdf

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be: The yaw/roll upset of the airplane resulting from the movement of the rudder surface to its blowdown limit. The rudder surface most likely deflected in a direction opposite to that commanded by the pilots as a result of a jam of the main rudder power control unit servo valve secondary slide to the servo valve housing offset from its neutral position and overtravel of the primary slide.

Findings

Occurrence #1: AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION
Phase of Operation: APPROACH

Findings
1. (C) HYDRAULIC SYSTEM - JAMMED
2. (C) AIRCRAFT CONTROL - CONFLICTING - FLIGHTCREW

Occurrence #2: LOSS OF CONTROL - IN FLIGHT
Phase of Operation: APPROACH

Factual Information

HISTORY OF FLIGHT

On June 9, 1996, Eastwind Airlines flight 517, a 737-200, N221US, experienced a yaw/roll upset about 2200 Eastern Daylight Time near Richmond, Virginia. The airplane was operating at an airspeed of about 250 knots and an altitude of about 4,000 feet msl in visual flight rules (VFR) conditions when the yaw/roll event occurred. The pilots were able to regain control of the airplane and land at the destination airport without further incident. None of the 53 airplane occupants were injured, and no damage to the airplane resulted from the incident.

As a result of previous Boeing 737 rudder anomalies, including the fatal accident involving USAir flight 427, a Boeing 737-300, which entered an uncontrolled descent and impacted terrain near Aliquippa, Pennsylvania, on September 8, 1994, Safety Board investigators initiated an investigation into this incident. The complete report of this incident investigation is contained in the final report of the USAir flight 427 investigation which can be found on the NTSB web site at the following link: http://www.ntsb.gov/publictn/1999/AAR9901.pdf . Additionally, all supporting factual information regarding this incident can be found in the public docket of the USAir flight 427 investigation. Excerpts of the factual narrative regarding the Eastwind incident from that report are presented here as follows:

During postincident interviews with the Eastwind crew, the captain reported that he was flying the airplane with the autopilot disengaged [1] and his feet resting lightly on the rudder pedals during the descent to land at Richmond. Both the captain and first officer reported that they had not encountered any turbulence or unusual weather during the flight, which originated from Trenton, New Jersey, or the approach to land. However, the captain said that, as the airplane descended through about 5,000 feet msl, he felt a brief rudder "kick" or "bump" on the right rudder pedal but that the pedal did not move. The captain stated that he glanced at the first officer's feet to see if he had contacted the rudder pedals but that the first officer had his feet flat on the floor.

Flight data recorder (FDR) information[2] and flight crew and flight attendant interviews indicated that, as the airplane descended through about 4,000 feet msl, the airplane yawed abruptly to the right and then rolled to the right. The captain stated that he immediately applied "opposite rudder and stood pretty hard on the pedal." The captain stated that, almost simultaneously with these rudder inputs, he applied left aileron.[3] Further, the captain consistently reported that the rudder pedal control felt stiffer than normal and did not seem to respond normally throughout the upset event. The first officer stated that he saw the captain "fighting, trying to regain control" and "standing on the left rudder." According to the captain, these flight control inputs slowed the yaw/roll event; however, the airplane "was still trying to roll," so he advanced the right throttle to compensate for the rolling tendency with differential power.[4] The captain stated that, after he made these inputs, the airplane appeared to move back toward neutral "for one or two seconds" and "might have momentarily banked left because of all the correction present" before returning abruptly to a right bank.

The flight crew performed the emergency checklist, which included disengaging the yaw damper. Subsequently, the upset event stopped, and the airplane flew normally for the remainder of the flight. The pilots reported a delay of several seconds between the

disengagement of the yaw damper and the end of the upset event.

During postincident interviews, the lead flight attendant of Eastwind flight 517 stated that she was standing in the aisle near the rear of the airplane cabin before the upset began. At that time, she heard a distinct thump from below but not directly underneath her feet. (The rear flight attendant also reported hearing a thump sound while the airplane yawed to the right) She reported that, immediately after the thump occurred, the airplane began "rocking with a violent back and forth motion.... The motions...lasted no more than fifteen seconds, were violent from start to finish, and appeared to come in cycles."

The FDR data revealed that the airplane rolled rapidly to the right about 10 degrees with a simultaneous heading change to the right of about 5 degrees per second. The FDR data also revealed that the airplane rolled back to the left, to a maximum left bank angle of approximately 15 degrees, while the right engine thrust increased. [5] (The airplane was in a 15-degree left bank for approximately 3 seconds and remained in a left bank for an additional six seconds while the engine thrust increased; however, the FDR recorded little heading change.) While the right engine pressure ratio (EPR) increased, the airspeed increased from about 250 to about 254 knots. The airplane's heading changed to the left; hesitated at about 242 degrees; and began a series of heading oscillations of decreasing magnitude, including a left heading excursion of 4.1 degrees and a right heading excursion of 5.6 degrees (both in 1 second). During the heading oscillations, the airplane's roll attitude also oscillated between an approximate wings-level attitude and 10 degrees left wing down (LWD). The heading and roll oscillations decreased while the airplane maintained an approximate constant heading of about 240 degrees.

AIRCRAFT INFORMATION

Postincident examination of the airplane's maintenance records revealed three flight crew-reported rudder-related events during the month preceding the incident. The first event occurred on May 14, 1996, when the captain of the June 9 Eastwind incident flight experienced a series of uncommanded "taps" on the right rudder pedal just after takeoff, which he stated felt "like someone hitting their foot on the right rudder." The captain returned to the departure airport and landed without further incident. As a result of

the uncommanded rudder movements reported to have occurred on May 14, the main rudder PCU was replaced that same day,[6] and the airplane was returned to service.[7] During a May 21 overnight inspection, rudder sweep and PCU leak examinations were conducted.

ADDITIONAL INFORMATION

Previous Event Experienced by the Captain.

The captain reported that the rudder pedal bumps he experienced on May 14 felt identical to the rudder pedal bump he felt at the onset of the yaw/roll event on June 9.

Additionally, the Eastwind flight 517 lead flight attendant was a cabin crewmember on the May 14 flight, during which the captain experienced the uncommanded rudder "taps." The flight attendant stated that she did not hear any sounds during the May 14 event and reported that the event was much less intense than the June 9 incident. She was in the front of the cabin during the May 14 event but was near the rear of the cabin during the June 9 incident.

The other two uncommanded yaw/roll events were reported to have occurred on June 1 and June 8, 1996. [8] As a result of these reports, the yaw damper transfer valve and the yaw

damper linear variable displacement transducer (LVDT) were removed and replaced on June 8. The incident pilots performed a postmaintenance test flight on the morning of June 9 and reported that the airplane performed normally, with no rudder system anomalies noted during the test flight. Because the airplane performed satisfactorily during the test flight, it was returned to service.

When Safety Board investigators examined the rudder system and the main rudder power control unit (PCU) after the June 9 incident, they observed that the rudder's yaw damper system had been adjusted such that the rudder neutral (at rest) position was 1.5 degrees to the left when the yaw damper system was engaged and the rudder trim was set at zero. The active yaw damper could move the rudder 1.5 degrees farther to the left of this neutral position and 4.5 degrees to the right of this neutral position with no aerodynamic loads. Postincident PCU testing at Parker's facility indicated that the yaw damper LVDT neutral position was incorrectly set. (The normal limit of yaw damper authority on the rudder, if properly set, would have been 3 degrees to the left and 3 degrees to the right of the rudder's neutral position.)

Additional examination and testing conducted by the Safety Board, Eastwind, and Boeing revealed that the wiring from the yaw damper coupler to the main rudder PCU was chafed and could have resulted in a short circuit, causing a full yaw damper command left or right. Additionally, examination of the yaw damper system revealed damage from infiltration of fluid that was consistent with, but not conclusive evidence of, an electrical fault. The main rudder PCU and yaw damper coupler were removed and replaced, new wiring was installed between the PCU and the yaw damper coupler, and the airplane was returned to service. To date, no further pilot complaints or maintenance write-ups regarding rudder "bumps" or other anomalous rudder motions have been reported on the incident airplane.

Flight Tests.

On June 22 through 24, 1996, the Safety Board conducted flight tests in the Eastwind flight 517 incident airplane, with Boeing, FAA, and Eastwind Airlines participation. The flight tests were to document the operation and limits of the airplane's yaw damper system, test and record the airplane's responses to various rudder inputs, and expose the captain of Eastwind flight 517 to various rudder inputs and document his reactions to and insights on the inputs. For the flight tests, the airplane's yaw damper system bias remained misadjusted so that it could command 1.5 degrees to the left and 4.5 degrees to the right of the rudder's trimmed position (as it was at the time of the incident). As with the wake vortex tests, additional test equipment and instrumentation were installed on the incident airplane to record and document the flights. [9]

During the ground and flight tests,[10] the incident airplane was operated with a Boeing flight test pilot in the left seat and an FAA flight test pilot in the right seat; the captain of Eastwind flight 517 and additional Boeing and FAA personnel were seated in the cabin. The first flight test was conducted at altitudes between 8,000 and 13,000 feet msl, at an airspeed of 250 knots, and with the yaw damper engaged and the flaps and landing gear retracted. Attempts were made to induce an in-flight yaw damper failure and subsequent hardover command through a series of rapid and abrupt rudder pedal and control wheel inputs; however, the flight test pilots were unsuccessful in inducing a yaw damper hardover. Before the second test flight, the incident yaw damper coupler was removed, and a different yaw damper coupler, a yaw damper fault insertion box, and associated wiring were installed to allow the flight test pilots to command a yaw damper hardover condition using an electrical signal.

The second flight test was also conducted at altitudes between 8,000 and 13,000 feet msl; at an airspeed of 250 knots; and with the yaw damper engaged, autopilot disengaged, and flaps and landing gear retracted. Yaw damper hardovers to the left and right were electronically commanded by the flight crew via the cockpit switchbox, and the maximum rudder and control wheel positions needed to stabilize the airplane were noted. Additionally, rudder pedal release tests were conducted using the following procedures:--

While maintaining straight and level flight using control wheel and rudder pedal inputs, right rudder trim was added in 1 degree increments, from 0 to 6 degrees trailing edge right rudder position.

-- Rudder pedal inputs were released.

-- Rudder position and control wheel input needed to control bank angle were noted.

During portions of the second flight test, the captain of Eastwind flight 517 occupied the right pilot seat previously occupied by the FAA flight test pilot [11] and controlled the airplane during a series of yaw damper hardover insertions and rudder pedal release conditions (including four yaw damper hardovers of 4.5 degrees right rudder, three rudder pedal releases from the 6 degrees right rudder trim position, and three rudder pedal releases from the 4 degrees right rudder trim position).

Recorded FDR and PADDS data indicated that the captain responded to the first yaw damper hardover 0.6 seconds after its initiation by stepping on the left rudder pedal. The flight test FDR data indicated that the airplane's bank angle increased to a maximum of about 4.5 degrees right wing down (RWD) and that its heading changed about 2 degrees (both in 1 second) before the airplane responded to the Eastwind flight 517 captain's recovery efforts. During the three subsequent yaw damper hardovers, the Eastwind flight 517 captain, at the direction of the Boeing flight test pilot, allowed the airplane to respond to the hardover condition for a few seconds before the captain responded with rudder pedal input.

When the Eastwind flight 517 captain was exposed to the 6 degrees right rudder pedal release test condition (during which FDR and PADDS equipment recorded a 4 degrees right heading excursion and a bank angle increase to 8 degrees RWD, both within 2 seconds), he stated "that was more like it." (The incident FDR data indicated a 4.1 degrees right heading change within 1 second and a maximum bank angle increase to 10 degrees RWD within 2 seconds.)

The Eastwind flight 517 captain indicated that the motion of the airplane during the portion of the second test flight, for which he was seated in the right pilot seat in the

cockpit, was similar to the airplane motion he recalled experiencing during the incident

and that the yoke pressure felt the same. However, the captain indicated that the rudder

response during the first and second tests seemed different from what he experienced

during the incident. He stated that the rudder felt stiffer and less effective during the actual incident.

Rudder Actuator Reversals During Servo Valve Secondary Slide Jams.

After the Safety Board's October 1996 thermal PCU tests, Boeing engineers began an independent detailed examination of the test data. Their review of the data indicated that the PCU servo valve responded slowly and erratically to the input commands when the secondary slide was jammed to the housing by the thermal shock and an input was applied to the external input arm. Boeing subsequently conducted tests using a new-production PCU that had been modified to simulate a jam of the secondary slide to the servo valve housing at various positions and then to simulate the application of a full rudder input to the PCU. These tests revealed that, when the secondary slide was jammed to the servo valve housing at certain positions, the primary slide could travel beyond its intended stop position because of bending or twisting of the PCU's internal input linkages (compliance).

This deflection allowed the primary slide to move to a position at which the PCU commanded the rudder in the direction opposite of the intended command (reversal).

Specifically, the tests revealed that, when the secondary slide was jammed at positions greater than 50 percent off neutral toward the extend or retract position and a full-rate command was applied to the PCU, the rudder would move opposite to the commanded position.

After studying the thermal test conditions in which the USAir flight 427 main rudder PCU jammed, the Safety Board attempted to determine the combined effects of PCU servo valve secondary slide jamming and input linkage deflections (compliance) to determine if the USAir flight 427 PCU was more susceptible to reversal than other servo valves. These tests were conducted in November 1996 on three PCUs: a new-production PCU, the USAir flight 427 PCU, and the Eastwind flight 517 PCU. For this series of tests, a tool was used to mechanically jam the secondary slides of all three PCUs to their respective servo valve housings. Manual inputs were then applied to the PCUs with the yaw damper energized and deenergized (no yaw damper command was applied in both cases). When inputs at a less-than-maximum rate were made to the PCU, all three PCUs operated normally. However, if the external input crank rate exceeded the capability of the PCU to respond at its maximum rate, the input caused deflection of the internal linkages (that is, caused them to bend or twist), resulting in overtravel of the primary slide and a reverse rudder response (that is, a response opposite to that commanded).

To identify the threshold for reversal, the Safety Board conducted tests on the three PCUs to determine the distance that the secondary slides had to be placed away from the

neutral ("no rudder command") position to result in rudder actuator reversal when an input force was applied to the PCU. The tests indicated that each of the three PCUs would stall (stop movement) or reverse when the secondary slide was jammed at or beyond the following positions (expressed as a percentage of full secondary slide travel from the neutral position):

New-production PCU: 38 percent in the extend direction, 54 percent in the retract direction.

-- USAir flight 427 PCU: 12 percent in the extend direction, 41 percent in the retract direction.

-- Eastwind flight 517 PCU: 17 percent in the extend direction, 30 percent in the retract direction.

On August 20, 1997, the Safety Board conducted additional tests on the USAir flight 427 and Eastwind flight 517 PCUs to determine the effects of a jammed secondary slide on the force and rate of rudder movement. For these tests, each PCU was installed in a test fixture at Parker that simulated the airplane installation, and the servo valve secondary slide was jammed with the jamming tool.

Eastwind Flight 517 Simulation Studies.

Pilot statements and data from Eastwind flight 517 indicated that the airplane was flying in relatively calm air[12] when it rolled and yawed to the right. The event lasted about 13 seconds. Postincident investigation revealed that the airplane's yaw damper had been rigged incorrectly so that the neutral point of the rudder would be 1.5 degrees to the left if the rudder trim knob were set to zero. Ground tests and measurements indicated that, in this incorrectly rigged condition, a yaw damper hardover would move the rudder an additional 1.5 degrees to the left or 4.5 degrees toward the right. Flight tests conducted in the Eastwind flight 517 airplane indicated that compliance within the rudder system would reduce the right yaw damper authority from 4.5 to 3.7 degrees (plus/minus 0.25 degrees error band) right during the flight conditions at the time of the upset.

The Safety Board's workstation-based simulator for a 737-200 airplane was used to simulate the events. Input to the simulation for engine thrust was based on data recorded on the FDR. The flight control surface position time histories needed for the simulations were not among the parameters recorded by the FDR and thus had to be estimated or derived. With the use of a detailed Boeing elevator model, the elevator input was derived from the control column position recorded by the FDR. The control wheel (aileron and spoilers) position input time histories were initially estimated from a kinematic analysis; the final control wheel position time histories were derived by iteration. The rudder was assumed to have been trimmed to its zero position at some time before the roll and yaw event to compensate for the yaw damper offset. (This action would result in the trim knob being

positioned about 1.5 degrees to the right, which is the position where the trim knob was discovered during postincident cockpit documentation.) The Safety Board's best-match simulation also assumed a rudder input similar to a yaw damper hardover to the right followed by a left rudder pedal input by the pilots to counter the yaw from this rudder input. The Board's simulation scenario then assumed that a rudder reversal occurred as a result of the left rudder pedal input while the PCU servo valve secondary slide was jammed to the servo valve housing.

Rudder position time histories were developed for a number of different conditions, including jams of the secondary slide to the servo valve housing at 100, 71, 55, 43, and 30 percent from the neutral position. The rudder position, once reversed, was assumed to remain at the jam-reduced blowdown limit (which is partly dependent on jam position within the servo valve, airspeed, and sideslip angle) for about 13 seconds, consistent with the period of heading shift recorded by the Eastwind flight 517 FDR during the incident. The timing of the rudder inputs was modified by iteration until the simulation produced heading time histories consistent with the FDR data.

The simulation assumed that, consistent with flight crew reports, the rudder PCU servo valve became unjammed at some point, enabling the captain to regain control of the airplane. Because there was no evidence of the rudder position after the captain regained control of the airplane, the simulation is meaningful only until 2210:42. This time is also when Boeing terminated the data in its simulations that were presented in its August 14, 1998, submission supplement.

The heading data that resulted from the simulation with the secondary slide jammed to the servo valve housing at the 55-percent position provided the best-match with the FDR heading data. This scenario assumed that the rudder pedal input resulted in a rudder reversal and rudder movement to the (reduced) blowdown limit (6.5 degrees) corresponding to the 55 percent jam.

Human Performance Aspects.

The captain of Eastwind flight 517 was 5 feet 10 inches tall. Postincident measurements in a cockpit identical to that of the incident airplane showed that, when the seat and rudder pedals were adjusted to the positions the captain normally used in landing, his left knee angle was 130 degrees when his left foot was pushing the left rudder pedal in its neutral position. The captain estimated that, during the incident, the left rudder pedal moved one and one-half inches forward of its neutral position in response to his efforts to depress it.

With the left rudder pedal in this position, the captain's left knee angle was 140 degrees when his left foot pushed the pedal. Further, when the captain demonstrated how he "stood on the

pedal" during the incident to gain greater pushing force, he used a raised posture in which his body moved upward by 2 inches (as measured at the shoulder). In this posture, his left knee angle was 145 degrees when he pushed on the left pedal, which was displaced one and one-half inches forward of its neutral position. Ergonomic literature indicates that this posture may have increased the captain's maximum leg force by as much as 35 percent compared with the United States Air Force (USAF) subject norm.

During postincident testing, the captain displayed a leg strength on a standard medical rehabilitation testing protocol that placed him below average compared with norms established by a sample of healthy, recreationally active adults. However, in allowing for the advantage that may have been provided by his effective knee angle, the Safety Board assumed that the captain could produce a maximum force in the 500-pound range when "standing" on the rudder pedal to oppose a rudder reversal.

On the Eastwind flight 517 airplane, a force of about 300 pounds would have been required to move the rudder pedal beyond its neutral position in a rudder reversal situation. Therefore, the captain's demonstration to investigators of the left rudder pedal

position that he recalled obtaining during the incident (about one and one-half inches forward of neutral) would correspond to an effort of about 450 pounds. This rudder pedal force is consistent with the Board's estimates based on the USAF data, adjusted for the captain's measured strength and knee angles.

Accordingly, on the basis of the available information, the Safety Board's simulation studies assumed that the captain's initial rudder pedal force was about 500 pounds. The simulation studies further assumed that this rudder pedal force was reduced later in the incident sequence.

Safety Recommendation Regarding Flight Data Recorder Information.

In a July 1, 1996, letter to the FAA, the Safety Board addressed the Eastwind flight 517 incident that had occurred the previous month. The Board believed that, under slightly

different circumstances, the Eastwind incident could have become the third fatal 737 upset accident for which there was inadequate FDR information to determine the cause. The Board also believed that, if the FAA had complied with the intent of Safety

Recommendation A-95-25, the Eastwind airplane would have been fitted with an FDR

that recorded the parameters necessary to better understand the events leading to the upset and develop corrective actions to prevent a future catastrophic 737 accident. In addition, the Board expressed its continued strong concern about the failure of the FAA to require the needed retrofit of the 737. The Board noted that more than 15 months had passed with no action taken on this important safety issue. As a result, Safety Recommendation A-95-25 had been placed on the Safety Board's Most Wanted Safety Improvements List. The Board once

again urged the FAA to take the necessary actions to meet the intent of this safety recommendation.

END NOTES

[1] The captain reported that it was his practice to disconnect the autopilot when descending through 10,000 feet msl and manually fly the airplane to landing.

[2] The FDR installed on the Eastwind flight 517 airplane, a Loral/Fairchild Data Systems model F1000 (S/N 00948), recorded 11 parameters. Altitude, airspeed, magnetic heading, engine pressure ratio (EPR) engine No. 1, EPR engine No. 2, and microphone keying were recorded at once-per-second sampling intervals. Parameters that were sampled more frequently than once per second were roll attitude and control column position versus time (two times per second), pitch and longitudinal acceleration (four times per second), and vertical acceleration (eight times per second). The CVR installed on the incident airplane, which was designed to preserve about 30 minutes of data, continued to record after the upset event and recorded over the data pertinent to the incident. Because no pertinent CVR data was available, the Safety Board referenced the incident times as follows: radar time equals FDR time in seconds minus 11,000 plus

2205:47 (local eastern standard time).

[3] During an interview 5 days after the incident, the captain estimated that he input about 40 to 45 degrees of control wheel displacement and stated that "the airplane seemed to hold in a 25 to 30 degree bank." A statement obtained from the first officer at the same time was consistent with the captain's estimates of control wheel input and bank angle. However, during an interview 10 days later, the captain indicated that a flight test in which the airplane rolled about 15 degrees "provided a better recreation of the motions of the airplane during the incident." (FDR data indicated that the incident airplane rolled between 10 and 15 degrees during the upset event.) Although both pilots estimated the captain's control wheel input during the incident to be about 40 to 45 degrees, Safety Board and Boeing kinematic studies indicated that the initial control wheel input was closer to 60 degrees. Additionally, during the interview 5 days after the incident, the captain estimated that he input about 3 to 4 inches of left rudder pedal displacement; however, in an interview 2 years later, the captain stated that the rudder pedals moved no more than 1 or 2 inches. The captain stated that he immediately put "a lot" of pressure on the rudder pedals but that they "did not go down to the floor."

[4] During postincident interviews, the captain told Safety Board investigators that his automatic decision to use differential power to counter the yaw/roll event reflected his experience in turbo propeller driven airplanes.

[5] About 5 seconds after the beginning of the upset, the EPR values for the right (No. 2) engine began to increase. The right engine EPR values increased to a maximum of 1.32; remained constant at 1.26 for 5 seconds; increased to 1.30 for 1 second; and then decreased to about 1.01, which was consistent with EPR values of the left (No. 1) engine for the entire incident.

[6] The Eastwind flight 517 main rudder PCU servo valve was assembled and tested at Parker on April 15, 1996.

[7] As a result of the uncommanded rudder movements reported to have occurred on May 14 (and another undocumented rudder event that occurred on or about May 31), on June 2, 1996, Eastwind issued Flight Crew Briefing Bulletin 96-03, which advised company pilots of the circumstances of the events and requested that pilots notify maintenance immediately if an unexplained yaw movement occurred.

[8] The airplane's June 1, 1996, logbook entry stated, "...[airplane] may have exp[erienced] 2 each [slight] rudder yaws [to] the left...approx[imately] 30 sec[onds] apart.... No rudder pedal movement...." The June 8, 1996, logbook entry stated, "with yaw damper off in level flight aircraft rolls to the right and the yaw damper test indicator also goes to the right."

[9] During the Eastwind flight tests, the PADDS system recorded 28 parameters, including 5 yaw damper-related parameters and 3 rudder system parameters, which provided valuable data for investigators. (The Eastwind flight 517 FDR recorded 11 parameters, none of which provided yaw damper or rudder position information.) The PADDS system recorded all data at higher sampling rates (20 times per second) than the FDR system that was installed on the airplane at the time of the incident. Additionally, a digital audiotape was installed to record CVR data beyond the normal 30-minute duration, and a Boeing noise recording system was installed to record noises emanating from the aft cabin and galley area during the flight tests (to determine the source of the thump noise described by the flight attendants from flight 517).

[10] Ground taxi tests were conducted before each of the two test flights to test the rudder and yaw damper system for anomalies that would preclude safe test flights and perform operational tests of the additional test equipment and instrumentation installed on the airplane.

[11] The FAA test pilot moved to the cockpit observer jumpseat and continued to control the yaw damper hardover

[12] Although the Eastwind flight 517 FDR data showed that the flight was mostly smooth, there were two positive spikes in the vertical load factor of about 1.2 Gs about 45 and 5 seconds before the event. There were coincident signatures in the longitudinal load factor data.

Pilot Information

Certificate:		**Age:**	
Airplane Rating(s):		**Seat Occupied:**	Unknown
Other Aircraft Rating(s):		**Restraint Used:**	
Instrument Rating(s):		**Second Pilot Present:**	
Instructor Rating(s):		**Toxicology Performed:**	
Medical Certification:	Unknown Unknown	**Last FAA Medical Exam:**	
Occupational Pilot:		**Last Flight Review or Equivalent:**	
Flight Time:			

Aircraft and Owner/Operator Information

Aircraft Make:	Boeing	**Registration:**	N221US
Model/Series:	B-737-201 B-737-201	**Aircraft Category:**	Airplane
Year of Manufacture:		**Amateur Built:**	No
Airworthiness Certificate:		**Serial Number:**	
Landing Gear Type:		**Seats:**	
Date/Type of Last Inspection:	Unknown	**Certified Max Gross Wt.:**	
Time Since Last Inspection:		**Engines:**	Unknown
Airframe Total Time:		**Engine Manufacturer:**	
ELT:		**Engine Model/Series:**	
Registered Owner:		**Rated Power:**	
Operator:	EASTWIND AIRLINES	**Operating Certificate(s) Held:**	Flag carrier (121)
Operator Does Business As:	EASTWIND AIRLINES	**Operator Designator Code:**	EW09

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual Conditions	**Condition of Light:**	Not Reported
Observation Facility, Elevation:	RIC, 0 ft msl	**Distance from Accident Site:**	0 Nautical Miles
Observation Time:	0000	**Direction from Accident Site:**	0°
Lowest Cloud Condition:	Scattered / 900 ft agl	**Visibility**	10 Miles
Lowest Ceiling:	Broken / 0 ft agl	**Visibility (RVR):**	0 ft
Wind Speed/Gusts:	4 knots /	**Turbulence Type Forecast/Actual:**	/
Wind Direction:	150°	**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:	30 inches Hg	**Temperature/Dew Point:**	22°C / 21°C
Precipitation and Obscuration:			
Departure Point:	, VA (RIC)	**Type of Flight Plan Filed:**	IFR
Destination:		**Type of Clearance:**	
Departure Time:	0000	**Type of Airspace:**	

Airport Information

Airport:		**Runway Surface Type:**	
Airport Elevation:		**Runway Surface Condition:**	
Runway Used:	0	**IFR Approach:**	
Runway Length/Width:		**VFR Approach/Landing:**	

Wreckage and Impact Information

Crew Injuries:	5 None	**Aircraft Damage:**	None
Passenger Injuries:	48 None	**Aircraft Fire:**	Unknown
Ground Injuries:	N/A	**Aircraft Explosion:**	Unknown
Total Injuries:	53 None	**Latitude, Longitude:**	

Administrative Information

Investigator In Charge (IIC):	THOMAS E HAUETER	**Report Date:**	11/30/2007
Additional Participating Persons:			
Publish Date:			
Investigation Docket:	NTSB accident and incident dockets serve as permanent archival information for the NTSB's investigations. Dockets released prior to June 1, 2009 are publicly available from the NTSB's Record Management Division at pubinq@ntsb.gov, or at 800-877-6799. Dockets released after this date are available at http://dms.ntsb.gov/pubdms/.		

The National Transportation Safety Board (NTSB), established in 1967, is an independent federal agency mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The NTSB makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

The Independent Safety Board Act, as codified at 49 U.S.C. Section 1154(b), precludes the admission into evidence or use of any part of an NTSB report related to an incident or accident in a civil action for damages resulting from a matter mentioned in the report. A factual report that may be admissible under 49 U.S.C. § 1154(b) is available here.