NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594
October 10, 1997

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT ADDENDUM
Rudder PCU Testing

A. ACCIDENT DCA-94-MA-076

Location: Aliquippa, PA
Date: September 8,1997
Time: 1904 Eastern Daylight Time
Aircraft: Boeing 737-300, N513AU

B. SYSTEMS GROUP

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C. SUMMARY

On September 8, 1994, at 1904 Eastern Daylight time, USAir flight 427, a Boeing 737-3B7 (737-300), N513AU, crashed while maneuvering to land at Pittsburgh International Airport, Pittsburgh, Pennsylvania. The airplane was being operated on an instrument flight rules (IFR) flight plan under the provisions of Title 14, Code of Federal Regulation (CFR), Part 121, on a regularly scheduled flight from Chicago, Illinois, to Pittsburgh. The airplane was destroyed by impact forces and fire near Aliquippa, Pennsylvania. All 132 persons on board were fatally injured.

D. DETAILS OF THE INVESTIGATION

General

The systems group, performed a series of tests at Parker Customer Services Organization (CSO) and Control Systems Division (CSD) in Irvine, California, August 19 and 20, 1997 to examine the effects of the main rudder power control unit (PCU) servo valve jamming, input linkage compliance, and yaw damper frequency response. The USAir flight 427 PCU, the Eastwind PCU, and a new production PCU (s/n 3313A) were used during various phases of the testing. On August 21, 1997, the systems group returned to Parker CSO to examine the effects of binding of the primary summing lever bearing.

The systems group formulated a test plan that consisted of four phases. The first and second phases were conducted at Parker CSO on August 19, 1997. The third phase was conducted at Parker CSD on August 20, 1997. The fourth phase was conducted at Parker CSO on August 21, 1997.

Phase 1-Rigid walking beam tests

The production PCU was installed into the test fixture. At this point, the PCU contained a production configuration walking beam assembly, P/N 69-35649. A secondary slide jamming tool was installed and the secondary slide rig neutral position was determined to be a measurement of 0.3223 inches. Rig neutral position is a reference measurement taken at the servo valve end cap that establishes the detent position of the secondary slide.

To begin the test, the secondary slide was jammed at approximately 50% of the effective secondary stroke from null (0.022 inches). The yaw damper was energized. No command was applied to the yaw damper.

Manual inputs were made to the PCU. With a normal input force, the PCU operated normally. If the input force was very large (large enough to comply the internal linkages, and overstroke the primary slide), the PCU would reverse.

The threshold of reversal was then determined by adjusting the slide jamming tool and inputting a manual command until the PCU stalled but did not reverse directions. The threshold was determined to be a jam about 40-50% of effective secondary slide stroke from null. With a jam less than 40%, the PCU would not reverse, even with very large input forces.

The production walking beam was removed and a specifically manufactured solid walking beam was installed into the PCU.

The slide jamming tool was re-adjusted to a jam of the secondary slide at 67% of effective secondary stroke from null (0.030 inches; a reference dimension of 0.292 inches). A manual input was made with the yaw damper energized. With a normal input force, the PCU operated normally. If the input force was very large (large enough to comply the internal linkages, and overstroke the primary slide), the PCU would reverse.

The slide jamming tool was re-adjusted to a jam of the secondary slide at 47% of effective secondary stroke from null (0.021 inches; a reference dimension of 0.301 inches). A manual input was made with the yaw damper energized. With a normal input force, the PCU operated normally. If the input force was very large (large enough to comply the internal linkages, and overstroke the primary slide), the PCU would reverse. The test was repeated with the yaw damper turned de-energized with identical results.

The slide jamming tool was then re-adjusted to a jam at 30% (a reference dimension of 0.3085) with identical results as above. At a 5% (a reference dimension of 0.320), the unit could be made to stall but could not be made to reverse. At a jam of 8.5 % (a reference dimension of 0.317 inches) the unit could only be made to reverse very slowly.

The tests were repeated on the Eastwind unit.

The secondary slide rig neutral was determined to be a measurement of 0.3255 inches. The secondary slide was jammed at 57% (a reference dimension of 0.296 inches) and 17% (a reference dimension of 0.318 inches) the unit could be made to reverse in both cases.

Phase 2-Yaw damper frequency response tests (±3° up to 50 Hz)

The purpose of phase 2 testing was to determine the yaw damper frequency response and yaw damper saturation limit. These tests examined the inner and outer feedback loop frequency response. With no manual input (yaw damper only) and with rapid manual inputs on top of the yaw damper cycling at 1, 3, 5, and 10 Hz. Phase 2 tests were conducted on the USAir 427 and production PCU's. The yaw damper and main ram functioned properly during all tests. There was no abnormal rudder response or yaw damper rudder interactions. The data is attached as attachment 1 to this report.

The production PCU was returned to its normal configuration (rigid walking beam removed, original walking beam installed).

The yaw damper was energized with a ± 3 ° sine wave input command from 0.10 Hz to 50 Hz (logarithmic sweep). The PCU ram and yaw damper amplitude ratios were plotted against the PCU ram and yaw damper phase lags. The yaw damper and main ram functioned properly during all tests. There was no abnormal rudder response or yaw damper rudder interactions. The data is attached as attachment 1 to this report

The test was repeated on the USAir 427 unit. With the same results as noted on the production unit.

Phase 3-PCU Output

On August 20, 1997, the systems group met at Parker CSD-Irvine to conduct tests on the USAir 427 and Eastwind PCUs. The PCU's were installed in a test fixture that simulated the airplane installation and allowed the measurement of PCU ram output force, position, and velocity. The PCU servo valve secondary was jammed with the slide jamming tool at neutral and various other positions between neutral and full effective secondary stroke.

Test Results-USAir 427 PCU

Note: No load was applied to the ram. However, the test fixture limited the travel of the ram so that at the end of travel (prior to bottoming the ram internally) the output force of the PCU could be measured.

Test number	Sec displacement/ %	Load (lb)	Velocity (in/sec)**
1	0.000/0%-null	5800	2.5
2 (redo 1)	0.000/0%-null	5800	2.5
3	0.0055/12%	----	0.31
*4 (redo 3)	0.0055/12%	----	0.34
5 (redo 4)	0.0055/12%	2900	0.31
6	0.010/22%	4400	0.75
*7	0.0225/50%	5200	no steady state
8 (redo 7)	0.0225/50%	5200	no steady state
*9 (redo 8)	0.0225/50%	5200	1.4
*10	0.044/98%	550	--
*11	0.032/71%	5400	2.1
12	0.000/0%-null	5800	2.5
13	0.023/50%	5100	1.4

** To convert in/sec to °/sec multiply x 12.69

* Notes:

- Test 4-Redo test 3. PCU back drive reversed. Torque motor couldn't hold input.
- Test 7-increased torque, reversed immediately. No piston-no steady state condition.
- Test 9-Low torque increased input torque. Manual inputs.
- Test 10- Full cross flow, won't reverse, backed off a little

- Between test 10 and 11 an 83% condition (0.0375) was ran without data taken with the same result as Test 10.

Test Results- Eastwind PCU

Note: No load was applied to the ram. However, the test fixture limited the travel of the ram so that at the end of travel (prior to bottoming the ram internally) the output force of the PCU could be measured.

Test number	Sec displacement/ %	Load (lb)	Velocity (in/sec)**
1	0.000/0%-null	5800	2.5
*2	0.0065/14%	----	---
*3	0.0065/14%	----	0.13
*4	0.010/22%	----	---
5	0.010/22%	2000	0.38
6	0.022/50%	4600	1.13
7	0.032/71%	5200	2.0

**To convert in/sec to °/sec multiply x 12.69

* Notes:

- Test 2 did not contact manifold stop. No data taken.
- Test 3 did not get to stall load. Test inadvertently stopped prior to stalling.
- Test 4 did not get data. Stopped short of stalling.

Phase 4-Primary summing lever bearing binding test

On August 21, 1997, the systems group met at Parker CSO to examine the effects of binding the primary summing lever bearing. A production summing lever was procured and the bearing inner race was intentionally welded to the bearing outer race in 2 places. (Note: the accident summing lever was not part of this test). The bearing was installed into the production actuator and a test was run to examine the effects of the jammed bearing.

The PCU was installed in the test fixture. The unit operated normally. After removing the link cavity cover, the group noticed that the lever appeared to rotate normally around the huckbolt. The lack of bearing rotation did not appear to affect the performance of the PCU. An ATP of the PCU was not performed.

[redacted]

Gregory Phillips
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National Transportation Safety Board

10/20/97