NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594
October 24, 1996

ADDENDUM TO
SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION

A. ACCIDENT DCA-94-MA-076

Location:	Aliquippa, Pennsylvania
Date:	September 8, 1994,1996
Time:	1904 Eastern Daylight Time
Aircraft:	Boeing 737-300, N513AU

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594
October 24, 1996

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION

A. ACCIDENT DCA-94-MA-076

Location:	Aliquippa, Pennsylvania
Date:	September 8, 1994
Time:	1904 Eastern Daylight Time
Aircraft:	Boeing 737-300, N513AU

B. SYSTEMS GROUP

Chairman:	Greg Phillips National Transportation Safety Board Aviation Engineering Division Washington, DC
Member:	Captain John Cox Air Line Pilots Association/USAir Coraopolis, PA
Member:	Ken Frey Federal Aviation Administration Aircraft Certification Office Seattle, WA
Member:	Dale A. Hoth Federal Aviation Administration Flight Standards District Office Coraopolis, PA
Member:	Richard Kullberg Boeing Commercial Airplane Group Seattle, WA

Member: Thomas C. Nicastro
USAir-Engineering
Pittsburgh, PA

Member: Steve Weik
Parker Hannifin
Irvine, CA

Member: Jack A. Wurzel
USAir-IAMAW
Pittsburgh, PA

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.

The systems group formulated a test plan to examine the effects of external inputs to the rudder cables from within the airplane's cargo compartment, rudder cable separations, and standby rudder actuator binding. The testing was conducted at Boeing facilities on a Boeing 737-200, N213US, owned by the Museum of Flight in Seattle, Washington.

The testing showed that the maximum rudder deflection from a 250 lbs. weight applied at airplane body station 295 was 3.2°. All other loads below 250 lbs. resulted in either no rudder deflection or a rudder deflection of less than 3.2°. The rudder cable cut testing showed that the rudder did not move when the cable was cut. The rudder pedal attached to the cable that was cut went to the floor and the pedal attached to the remaining cable maintained the ability to move the rudder in the direction of the intact cable.

Additional testing was conducted to examine the effects of binding of the airplane's standby rudder actuator and the effects of failures of the airplanes hydraulic systems on the rudder system operation. The testing indicated that when a standby rudder actuator input shaft and bearing with galling similar to that found on USAir flight 427 was installed into the test airplane, the rudder system functioned normally. Testing conducted with an input shaft galled similar to United Airlines flight 585[1] indicated that a full 3° yaw damper command would result in 5° rudder

[1] United Airlines flight 585 accident, Colorado Springs, CO, March 3, 1991. NTSB report AAR-92/06

movement to the left and 6° rudder movement to the right. Failures of the test airplane's A hydraulic system did not significantly affect the operation of the rudder system.

When the standby rudder actuator input shaft was hard jammed at 3° left, 3° right, and at the main rudder PCU body stop, the rudder moved to an off neutral position when the hydraulic system was powered. In every case, the rudder could be centered by applying rudder pedal force to oppose the offset. With the standby rudder actuator input shaft and bearing jammed at the neutral position, there was no initial offset to the rudder.

Another test was conducted to simulate the rudder system effects of introducing a foreign object or block between the main rudder PCU input crank and the PCU manifold body stop. Testing indicated that with the crank movement blocked, a sustained left yaw damper command caused the rudder to travel to its limit. With the block moved to the other side of the crank arm, a sustained right yaw damper command caused the rudder to travel to its limit. The movement in either case could not be stopped until the blocking material fell from its position between the body stop and the input crank. In some cases rudder pedal input in the direction of the rudder movement resulted in the blocking material falling free whereby rudder control was regained.

D. DETAILS OF THE INVESTIGATION

On February 27 through March 5, 1996, the systems group met at the Boeing Commercial Airplane Group facilities in Renton, Washington, to perform testing to examine the effects of standby rudder actuator binding, rudder cable separation, and external loads applied to rudder cables.

A B737-200 airplane was used for the rudder system tests. The test airplane's rudder feel and centering system was a hydromechanical system that can vary rudder centering forces as a function of airspeed. The B737-300 rudder feel and centering mechanism uses a mechanical system that does not vary centering forces as a function of airspeed.

The group determined that pitot pressure equivalent to an airspeed of 125 kts supplied to the test airplane's rudder feel and centering system, through the test airplane's rudder feel and centering mechanism's pitot tube resulted in feel and centering characteristics similar to the B737-300's mechanical system.

All yaw damper electrical commands for rudder system testing were generated by the use of a force function generator. The yaw damper dwell and amplitude were controlled by the test operator.

A series of instrumentation verification tests were conducted on the test airplane. These tests were conducted on February 22 and 26, 1996 prior to the systems group arrival but were approved by the systems group. The data collected during these tests is included as attachments 1 and 2, tests 001-05 and 001-06, respectively.

Data collected during the systems group tests follows this report as:

Attachment 1, Test 001-05, 2/22/96
Attachment 2, Test 001-06, 2/26/96
~~Attachment 3, Test 001-07, 2/27/96~~
Attachment 4, Test 001-08, 2/29/96
Attachment 5, Test 001-09, 3/1/96
Attachment 6, Test 001-10, 3/4/96
Attachment 7, Test 001-11, 3/5/96

1.0 Rudder system effects of external inputs to the rudder cables

The objective of the external input tests was to examine the effects of external forces applied to the rudder cable. Testing was conducted by pulling down on the rudder cables from within the airplane's cargo compartment at aircraft body station 295. The tests were performed on February 27, 1996, as test number 001-07.

The following test sequence was performed:

1. The aircraft rudder system components were verified to be operable in accordance with in-service aircraft standards.
2. With A and B system hydraulic pressure on the airplane, the rudder was cycled to verify instrumentation and operational limits.
3. From within the forward cargo compartment an incremental load of 50, 100, 150, 200, 250 pounds was applied to rudder cable R_b[2].
4. An incremental load of 200 and then 250 pounds was applied to rudder cable R_a.

1.1 External inputs test results summary

Condition B1.39.0935.201 involved applying 50 lbs. load to the R_b cable. There was no rudder deflection. Condition B1.39.0935.202 involved applying 100 lbs. load to the R_b cable. There was no rudder deflection. Condition B1.39.0935.203 involved applying 150 lbs. load to the R_b cable. The rudder deflected 2.1°. Condition B1.39.0935.203 involved applying 200 lbs. load to the R_b cable. The rudder deflected 3.2°. Condition B1.39.0935.206 involved applying 200 lbs. load to the R_a cable. The rudder deflected 1.07°. Condition B1.39.0935.207 involved applying 250 lbs. load to the R_a cable. The rudder deflected 2.28°.

[2] Rudder cable R_b is connected to the left rudder pedals. R_a is connected to the right rudder pedals.

2.0 Rudder systems effects of rudder cable separations

The objective of the rudder cable separation tests was to examine the effects of rudder cable separations and record cockpit sounds associated with the separations. A cockpit voice recorder (CVR) was operated during the tests and the CVR group recorded the sounds associated with the rudder cable separations. The rudder cables were cut by hand at body stations 360 and 259.5. A visual examination of rudder cable positions was conducted after the separation. The tests were performed on February 27, 1996, as test number 001-07.

The following test sequence was performed:

1. The aircraft rudder system components were verified to be operable in accordance with in-service aircraft standards.
2. With hydraulic system pressure on the airplane, the rudder was cycled to verify instrumentation and operational limits.
3. Slow rudder stop-to-stop sweeps were performed.
4. With the pilot's feet off the rudder pedals, the R_b cable was cut at aircraft body station 360 and the effects of the cable separation (sounds, and rudder pedal and rudder surface movement) were recorded.
5. The left and right rudder pedals were depressed and the rudder system response was measured.
6. The rudder cable was replaced.
7. With the pilot's feet lightly contacting both rudder pedals, the R_b rudder cable was cut at aircraft body station 259.5. The effects of the cable separation were recorded.
8. The left and right rudder pedals were depressed and the rudder system response was measured.

2.1 Rudder cable separation test results summary

Condition B1.39.0935.101 recorded the cutting of the rudder cable. A load "bang" was heard as the cable was cut at body station 360; the rudder did not move. Condition B1.39.0935.102 recorded the end positions of the rudder cables after the cut. Condition B1.39.0935.103 recorded the rudder operation after the cable cut.

After a new cable was installed and the rigging was checked, condition B1.39.0935.104 recorded the second cable cut at body station 259.5. The rudder did not move as a result of the cable cut. The rudder pedal on the cable that was cut moved to the -5° position. Condition B1.39.0935.106 recorded the rudder operation after the cable cut.

The CVR group's findings are contained in a separate report.

3.0 Rudder system effects of standby rudder actuator binding

The objectives of the standby rudder actuator binding tests were to examine the effects of ~~variable input shaft binding~~ forces and input shaft binding at different positions. The effects of hydraulic system failures on the rudder system ~~operation with and without standby actuator~~ binding and with yaw damper operation were also examined.

3.1 Rudder system baseline operation

A baseline was established by verifying that the aircraft rudder system rigging and main and standby rudder PCU installations were accordance with in-service aircraft standards. The rudder system was cycled to verify instrumentation and operational limits. The testing was conducted on February 29, 1996, as test 001-08.

Baseline testing involved collecting data for the test airplane in its unaltered state. Test conditions B1.39.0928.101 thru .111 involved operating the rudder system and measuring the effects. Different yaw damper inputs were made at a 0.3 Hz dwell.

3.2 Rudder system effects of standby rudder actuator input shaft and bearing binding similar to USAir flight 427

After establishing a baseline, the standby rudder actuator was removed from the airplane and a input shaft and bearing with galling similar in area, size, and appearance to the USAir flight 427 input shaft and bearing were installed into the standby rudder actuator. The shaft and bearing was provided by USAir and had been removed from an in-service aircraft. The objective of the test was to determine the effects of the galling on the rudder system's operation. The tests were performed on February 29, 1996, as test number 001-08.

The following test sequence was followed to examine the effects on the rudder system:

1. The input shaft and bearing were installed into the standby rudder actuator.
2. The rudder was cycled through full deflection in both directions with rudder pedal inputs.
3. The rudder system was operated with only the B and standby hydraulic systems operating.
4. Yaw damper commands of $\pm 3°$ at 0.3 Hz were input to the main rudder PCU.
5. The rudder system was operated with the rudder pedals in both directions.
6. Yaw damper commands of $\pm 1°$ at 0.3 Hz were input to the main rudder PCU.
7. The rudder system was operated with the rudder pedals in both directions.
8. The rudder system was operated with the A, B, and standby hydraulic systems operating.
9. Yaw damper commands of $\pm 3°$ at 0.3 Hz were input to the main rudder PCU.
10. The rudder system was operated with the rudder pedals in both directions.
11. Yaw damper commands of $\pm 1°$ at 0.3 Hz were input to the main rudder PCU.
12. The rudder system was operated with the rudder pedals in both directions.

3.2.1 Standby rudder actuator similar to USAir flight 427 test results summary

The tests showed that galling of the standby rudder actuator input shaft and bearing similar to that found on USAir flight 427's actuator did not adversely affect the rudder system's performance. Conditions B1.39.0928.201 thru .210 record the results of these tests.

3.3 Rudder system effects of standby rudder actuator binding with variable binding

After the preceding tests, the standby rudder actuator was replaced with a standby actuator capable of fixing the actuator input shaft at variable positions. The objective of the tests were to determine the effects of different levels of binding at the standby rudder actuator input shaft and bearing interface.

USAir provided an actuator for the tests that consisted of a standby rudder actuator that had been modified by welding an extension to the actuator's input shaft. The actuator also had a clamping device attached to the actuator body that allowed for variable clamping forces on the actuator shaft extension by tightening two bolts on the clamp block to apply friction against the actuator shaft extension. After tightening the clamping device, a spring scale was used to test the force required to move the end of the actuator input arm before it was installed in the airplane or pressurized.

The tests were initially conducted with 60-70 lbs force required to move the input shaft arm. After those tests were completed, the clamping device was reset to generate approximately 100 lbs of force required to move the input arm.

The following test sequence was followed:

1. The standby actuator that repeatedly binds with approximately 60-70 pounds of force was installed into the test airplane.
2. The rudder was cycled with rudder pedal inputs through full deflection in both directions without hydraulic pressure on the airplane.
3. The hydraulic systems were pressurized and the rudder was operated in both directions.
4. Yaw damper command signals of $\pm 3°$ at 0.3 Hz were input to the main rudder PCU.
5. The rudder was cycled through full deflection in both directions with rudder pedal inputs while the yaw damper was cycling.
6. A full left rudder step command was input to the yaw damper.
7. The rudder was then centered using the rudder pedals.
8. A full right rudder step command was input to the yaw damper.
9. The rudder was then centered using the rudder pedals.
10. The A hydraulic system was disabled and the standby hydraulic system was energized.
11. The rudder was operated in both directions

12. Yaw damper commands of ± 3° were input to the main rudder PCU.
13. The rudder system was operated with the rudder pedals in both directions while the yaw damper was cycled from ± 1° at 0.3 Hz.
14. Yaw damper command signals of ± 1° at 1 Hz were input to the main rudder PCU.
15. Yaw damper command signals of ± 3° at 1 Hz were input to the main rudder PCU.

The standby rudder actuator was then reset for approximately 100 lbs. of binding force (as measured at the end of the input arm).

The following test sequence was performed:

1. The rudder was cycled with rudder pedal inputs through full deflection in both directions without hydraulic pressure on the airplane.
2. The hydraulic systems were pressurized and the rudder was operated in both directions with the rudder pedals.
3. A full left rudder step command was input to the yaw damper.
4. The rudder was then centered using the rudder pedals.
5. A full right rudder step command was input to the yaw damper.
6. The rudder was then centered using the rudder pedals.
7. The rudder was operated in both directions with the rudder pedals.
8. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
9. The rudder was cycled through full deflection in both directions with rudder pedal inputs while the yaw damper was cycling.
10. The A hydraulic system was disabled and the standby hydraulic system was energized.
11. The rudder was operated in both directions
12. Yaw damper commands of ± 3° were input to the main rudder PCU.

3.3.1 Standby rudder actuator variable binding test results summary

The tests showed that with 60-70 lbs. of binding force, the rudder could travel 7° to the left with a full left yaw damper command and 8° to the right with a full right yaw damper command. A force of 45 lbs on the appropriate rudder pedal would restore the rudder to the neutral position. Disabling the A hydraulic system had negligible adverse effect on the rudder system operation.

With 100 lbs of binding force, the rudder could travel 8° to the left or right with a full left or right yaw damper command, respectively. A force of 60 lbs on the left rudder pedal would restore the rudder to the neutral position. A force of 30 lbs on the on the right rudder pedal would restore the rudder to the neutral position. Disabling the A hydraulic system had negligible adverse effect on the rudder system operation.

Conditions B1.39.0928.301 thru .316 document the findings of the 60-70 lbs binding tests. Conditions B1.39.0928.318 thru .324 document the findings of the 100 lbs binding tests.

3.4 Rudder system effects of hard jams of the standby rudder actuator input shaft and bearing

After completion of the variable binding tests, tests were conducted with a standby rudder actuator provided by Boeing that had been modified to allow the actuator input arm to be fixed at any position. The actuator was modified by replacing the actuator's actuator valve with an adjustable device that fixed the input shaft at varying positions. The input shaft and ball were also modified to accommodate the higher forces in binding. The modification of the actuator allowed adjustment to the shaft position through the hydraulic system return port. This modification precluded any pressurization of the actuator during testing.

The actuator was used to test the effects of hard jamming of the input shaft and bearing at the standby rudder actuator neutral position, the standby rudder actuator input arm position for a 3° rudder input, and the standby rudder actuator input arm position for a full maximum rate rudder input limited by the main rudder PCU external manifold (body) stop.

The following test sequence was performed to examine the effects of hard binding/jamming on the standby rudder actuator input arm at neutral:

1. The standby rudder actuator was adjusted to simulate a hard jam at the neutral standby rudder input arm position.
2. The rudder was cycled with rudder pedal inputs through full deflection in both directions with hydraulic pressure on the airplane.
3. A full left rudder step command was input to the yaw damper.
4. The rudder was then centered using the rudder pedals.
5. A full right rudder step command was input to the yaw damper.
6. The rudder was then centered using the rudder pedals.
7. Another full left rudder step command was input to the yaw damper.
8. The rudder was then centered using the rudder pedals.
9. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
10. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
11. The rudder system was operated with the rudder pedals in both directions while the yaw damper was cycled from ± 1° at 0.3 Hz.
12. The rudder was then centered using the rudder pedals.
13. The rudder trim system was used to center the rudder.

The following test sequence was performed to examine the effects of hard binding/jamming of the standby rudder actuator input arm at the position it would be in for a full +3° (left) rudder input command from the main rudder PCU:

1. The standby rudder actuator was adjusted to simulate a hard jam at the +3° standby rudder input arm position.
2. The A and B hydraulic systems were pressurized.
3. The rudder was centered with the rudder pedals.
4. The rudder was cycled with rudder pedal inputs through full deflection in both directions with hydraulic pressure on the airplane.
5. A full left rudder step command was input to the yaw damper.
6. The rudder was then centered using the rudder pedals.
7. A full right rudder step command was input to the yaw damper.
8. The rudder was then centered using the rudder pedals.
9. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
10. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
11. The rudder system was operated with the rudder pedals in both directions while the yaw damper was cycled from ± 1° at 0.3 Hz.
12. The rudder was then centered using the rudder pedals.
13. The rudder trim system was used to center the rudder.

The following test sequence was performed to examine the effects of hard binding/jamming of the standby rudder actuator input arm at the position it would be in for a full -3° (right) rudder input command from the main rudder PCU:

1. The standby rudder actuator was adjusted to simulate a hard jam at the -3° standby rudder input arm position.
2. The A and B hydraulic systems were pressurized.
3. The rudder was centered with the rudder pedals.
4. The rudder was cycled with rudder pedal inputs through full deflection in both directions with hydraulic pressure on the airplane.
5. A full left rudder step command was input to the yaw damper.
6. The rudder was then centered using the rudder pedals.
7. A full right rudder step command was input to the yaw damper.
8. The rudder was then centered using the rudder pedals.
9. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
10. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
11. The rudder system was operated with the rudder pedals in both directions while the yaw damper was cycled from ± 1° at 0.3 Hz.
12. The rudder was then centered using the rudder pedals.
13. The rudder trim system was used to center the rudder.

The following test sequence was performed to examine the effects of hard binding/jamming of the standby rudder actuator input arm at the position it would be in for a full maximum rate rudder input limited by the main rudder PCU external manifold (body) stop:

1. The standby rudder actuator was adjusted to simulate a hard jam of the input shaft while at the main rudder PCU external manifold (body) stop input arm position.
2. The A and B hydraulic systems were pressurized.
3. The rudder was cycled with rudder pedal inputs through full deflection in both directions.
4. The rudder was centered with the rudder pedals.

<u>3.4.1 Standby rudder actuator hard jam effects test results summary</u>

The tests showed that with the standby rudder actuator input shaft hard jammed at neutral, the rudder could travel 6° to the left with a full left yaw damper command and 4° to the right with a full right yaw damper command. A force of 45 lbs or 55 lbs on the appropriate rudder pedal, respectively, would restore the rudder to the neutral position. With a jam at neutral and no yaw damper commanded input, the rudder was at neutral (0°).

With the standby rudder actuator input shaft bound at 3° (full yaw damper command capability) left, the rudder could travel 10° to the left with a full left yaw damper command and 3° to the right with a full right yaw damper command. A force of 25 lbs or 95 lbs on the appropriate rudder pedal, respectively, would restore the rudder to the neutral position. With a jam at the full left yaw damper position and no yaw damper commanded input, the rudder went 2° left of neutral position.

With the standby rudder actuator input shaft bound at 3° (full yaw damper command capability) right, the rudder could travel 2° to the left with a full left yaw damper command and 13° to the right with a full right yaw damper command. A force of 110 lbs or 30 lbs on the appropriate rudder pedal, respectively, would restore the rudder to the neutral position. With a jam at the full right yaw damper position and no yaw damper commanded input, the rudder went 4° right of neutral position.

With the standby rudder actuator input shaft bound at a position it would be in for a full maximum rate rudder input (to the left) limited by the main rudder PCU external manifold (body) stop, the rudder went 19° left of neutral position with a full yaw damper command. With a full yaw damper command input to the main rudder PCU, a force of 65 lbs restored the rudder to the neutral position. A force of 140 lbs was required to restore the rudder to neutral without any yaw damper command.

Conditions B1.39.0928.401 thru .412 document the findings of tests for jamming at neutral. Conditions B1.39.0928.501 thru .513 document the findings for jamming at 3° left.

Conditions B1.39.0928.613 thru .615 and B1.39.0928.620 thru .627 document the findings for jamming at 3° right.

Conditions B1.39.0928.616 thru .618 document the findings for a standby rudder actuator input shaft jammed at a position for a full maximum rate rudder input (to the left) limited by the main rudder PCU external manifold stop.

3.5 Rudder system effects of a "naturally" galled standby rudder actuator input shaft and bearing

The objective of the testing was to create a standby rudder actuator input shaft and bearing with characteristics similar to those found on the United Airlines flight 585 accident airplane's standby rudder actuator and test its effects on the B737 rudder system.

A standby rudder actuator input shaft and bearing were manufactured by Boeing with controlled tolerances to "naturally" induce galling after several cycles of operation. After galling the shaft and bearing, the binding forces were measured as approximately 60 lbs. The input shaft and bearing were then installed into a standby rudder actuator and installed into the test airplane. The standby rudder actuator could not be pressurized after modification.

The following test sequence was performed to examine the rudder system effects of "natural" galling of the standby rudder actuator input arm:

1. The A and B hydraulic systems were pressurized (Note: the standby actuator could not be pressurized).
2. The rudder was cycled with rudder pedal inputs through full deflection in both directions with hydraulic pressure on the airplane.
3. A full left rudder pedal command was input.
4. The rudder was then centered using the rudder pedals.
5. A full right rudder pedal command was input.
6. The rudder was then centered using the rudder pedals.
7. A full left rudder pedal command was input.
8. The rudder was then centered using the rudder pedals.
9. A full right rudder pedal command was input.
10. The rudder was then centered using the rudder pedals
11. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
12. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
13. Yaw damper command signals of ± 3° at 1 Hz were input to the main rudder PCU (repeated 6 times to induce additional galling).
14. Yaw damper command signals of ± 1° at 1 Hz were input to the main rudder PCU.
15. Yaw damper command signals of ± 3° at 1 Hz were input to the main rudder PCU.

16. Yaw damper command signals of ± 3° at 1 Hz were input to the main rudder PCU.
17. The rudder system was operated with the rudder pedals in both directions.
18. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
19. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
20. The rudder system was operated with the rudder pedals in both directions.
21. The rudder system was operated with the rudder pedals in both directions at a quicker rate.
22. Hydraulic system turned off.
23. The rudder system was operated with the rudder pedals in both directions.

3.5.1 Rudder system effects of a "naturally" galled standby rudder actuator input shaft and bearing summary results

With the standby rudder actuator input shaft and bearing naturally galled, the rudder could travel 5° to the left with a full left yaw damper command and 6° to the right with a full right yaw damper command.

Conditions B1.39.0928.701 thru .707 document the findings of the testing.

3.6 Rudder system effects of a second "naturally" galled standby rudder actuator input shaft and bearing

A second standby rudder actuator input shaft and bearing were manufactured by Boeing with sufficiently controlled tolerances to "naturally" induce galling after several cycles of operation. After galling the shaft and bearing, the binding forces were measured as approximately 60 lbs. The input shaft and bearing were then installed into a standby rudder actuator and installed into the test airplane. The standby rudder actuator differed from the actuator previously discussed in section 3.5 in that it could be pressurized.

The following test sequence was followed:

1. The A and B hydraulic systems were pressurized
2. The rudder was cycled with rudder pedal inputs through full deflection in both directions.
3. A full left rudder pedal command was input.
4. The rudder was then centered using the rudder pedals.
5. A full right rudder pedal command was input.
6. The rudder was then centered using the rudder pedals.
7. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
8. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.

9. Yaw damper command signals of ± 3° at 1 Hz were input to the main rudder PCU (repeated 6 times to induce additional galling).
10. The rudder system was operated with the rudder pedals in both directions.
11. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
12. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
13. The rudder system was operated with the rudder pedals in both directions.
14. A hydraulic system turned off.
15. The rudder system was operated with the rudder pedals in both directions.
16. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
17. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
18. The A, B, and standby rudder hydraulic systems were pressurized.
19. The rudder system was operated with the rudder pedals in both directions.
20. Yaw damper command signals of ± 3° at 0.3 Hz were input to the main rudder PCU.
21. Yaw damper command signals of ± 1° at 0.3 Hz were input to the main rudder PCU.
22. The rudder pedals were operated while the ± 1° at 0.3 Hz signal was driving the rudder

3.6.1 Rudder system effects of a second "naturally" galled standby rudder actuator input shaft and bearing summary results

With the standby rudder actuator input shaft and bearing naturally galled, the rudder could travel 6° to the left with a full left yaw damper command and 6° to the right with a full right yaw damper command. Disabling the A hydraulic system or operating all 3 hydraulic systems simultaneously did not produce any adverse effects on the system performance.

Conditions B1.39.0928.801 thru .811 documents the findings of the testing.

3.7 Rudder system effects of jamming foreign materials between the main rudder PCU input crank and the main rudder PCU manifold body stop

A test was conducted to simulate the rudder system effects of introducing a foreign object or block between the main rudder PCU input crank and the PCU manifold body stop.

The following test sequence was performed:

1. A piece of folded paper was inserted between the manifold body stop and input crank arm.
2. The A and B hydraulic systems were powered.
3. A left yaw damper hardover command was input to the main rudder PCU.
4. The rudder pedal was pushed to release the blockage.

5. A right yaw damper hardover command was input to the main rudder PCU.
6. The rudder pedal was pushed to release the blockage.

3.7.1. Rudder system effects of jamming foreign materials test results summary

Testing indicated that with the crank movement blocked, a sustained left yaw damper command caused the rudder to travel to its limit. Likewise with the block moved to the other side of the crank arm, a sustained right yaw damper command caused the rudder to travel to its limit. The movement in either case could not be stopped until the blocking material fell from its position between the body stop and the input crank. In some cases rudder pedal input in the direction of the rudder movement resulted in the blocking material falling free and rudder control was regained.

[redacted]

Gregory Phillips
Systems Group Chairman
National Transportation Safety Board

10/25/96