NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

AIRWORTHINESS GROUP FACTUAL REPORT ADDENDUM 1

March 26, 2007

A. ACCIDENT DCA06FA058

Location: Memphis, Tennessee
Date: July 28, 2006
Time: 1125 Central Daylight Time (CDT)
Aircraft: FedEx Express Flight 630, McDonnell-Douglas (Boeing) MD-10-10F, N391FE

B. AIRWORTHINESS GROUP

Chairman: Clinton R. Crookshanks
National Transportation Safety Board
Denver, Colorado

Member: Craig Valentine
Crane, Hydro-Aire Division
Burbank, California

Member: Ken Sujishi
Federal Aviation Administration
Lakewood, California

Member: William Levin
Air Line Pilots Association
Memphis, Tennessee

Member: Neal Gilleran
The Boeing Company
Long Beach, California

Member: Keith Herbert
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C. SUMMARY

On July 28, 2006, about 1125 Central Daylight Time, FedEx Express (FedEx) flight 630, a McDonnell-Douglas (Boeing) MD-10-10F (MD-10), N391FE, crashed while landing at Memphis International Airport (MEM), Memphis, Tennessee. The left main landing gear collapsed after touchdown on runway 18R, and the airplane came to rest on the runway. After the gear collapsed, a fire developed on the left side of the airplane. The two flight crewmembers received minor injuries during the evacuation, and one nonrevenue FedEx pilot was not injured. The postcrash fire substantially damaged the airplane's left wing and portions of the left side of the fuselage. Flight 630 departed from Seattle-Tacoma International Airport (SEA), Seattle, Washington, and was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 on an instrument flight rules flight plan.

D. DETAILS OF THE INVESTIGATION

1.0 Test Plan

The Brake Control Unit (BCU), two Dual Brake Control Valves (DBCV), two Anti-Skid Manifolds (ASM), two Dual Wheelspeed Transducers (WST), and two Single WST's were removed from the accident airplane and shipped to Crane Aerospace, Hydro-Aire Division, in Burbank, CA. All components except the DBCV's were subjected to their respective acceptance tests in the "as received" condition. Following the acceptance testing, the group convened at the Hydro-Aire facility on September 25-29, to perform additional testing of the DBCV's and ASM's on a brake simulation fixture specifically designed for the MD-10-10F carbon brake program. The testing involved two phases; the Phase 1 objective was to measure the characteristics and stability of the brake pressure output from the DBCV's in response to brake pedal inputs with no anti-skid control while the Phase 2 objective was to investigate the stability of the anti-skid control system during a simulation of the accident landing and examine the effect of brake torque and cooling of the brake fluid on the stability of the system.

2.0 Acceptance Testing

BCU, P/N 142-109, S/N 108
The unit failed the initial BIT erase maintenance memory test. The test was re-run and the unit passed. During the initial testing the maintenance memory screen was activated causing the failure. The test results are in Attachment 1.

Dual WST, P/N 140-289, S/N 129
The mounting flange exhibited gouging. The unit passed the test with the exception that the secondary output for spoiler deployment was measured as 4.8 volts peak-to-peak, it should be 5.0 volts minimum. The test results are in Attachment 2.

Dual WST, P/N 140-289, S/N 156
The unit exhibited no irregularities and passed the test. The test results are in Attachment 2.

Single WST, P/N 140-287, S/N 138
The unit exhibited nicks on the adapter flange and passed the test. The test results are in Attachment 3.

Single WST, P/N 140-287, S/N 171
The unit exhibited no irregularities and passed the test. The test results are in Attachment 3.

ASM, P/N 33-177, S/N 113
The unit was received with the C and D port fuse fittings broken and pulled from the unit. The fittings are a flareless ring locked port connection. The fuses were replaced in order to run the test. The unit passed all tests with the exception of the low flow fuse shutoff test. The upper limit of the flow is 1557 cc per the test. Port A measured 1600 cc and port B measured 1640 cc. Current versus brake pressure was plotted for all four valves and exhibited no anomalies. The test results are in Attachment 4.

ASM, P/N 33-177, S/N 114
The unit was received with the D port fuse fitting broken and pulled from the unit and the servo cover on servo D was gouged. A broken airplane mounting bolt was located in the middle mounting thread on the A port side of the unit. The fuse was replaced in order to run the test. Numerous failures were noted during the test. The plot of current versus brake pressure at port A indicated a pressure shift such that the maximum pressure obtained was 2300 psig at the 5 mA quiescent current. The plot of port C indicated an infinite gain (loss of control) at approximately 1850 psig to 3000 psig. The plot of port D indicated an infinite gain (loss of control) at approximately 2000 psig to 3000 psig. The internal leakage of port C was measured to be 860 cc, the maximum allowed is 800 cc. The high flow fuse shutoff leakage at port A was measured to be 1360 cc, the maximum allowed is 1310 cc. The test results are in Attachment 5.

DBCV, P/N 35950-505, S/N 444076
No acceptance test performed since it was not manufactured by Hydro-Aire.

DBCV, P/N 35950-505, S/N 438942
No acceptance test performed since it was not manufactured by Hydro-Aire.

3.0 Dual Brake Control Valve Testing

The DBCV's were installed in the hydraulic simulator to test the brake pressure output in relation to a specified input. The first part of the test involved manual actuation of the DBCV slowly to full travel and release back to zero while recording the input arm angle versus output pressure. The tests on both DBCV's were performed with ASM, S/N 114, and with the left side of the DBCV connected to the short side of the simulator. The input angle was measured with a potentiometer on the actuation lever and the brake pressure was measured at the brake for each of the four inputs from the anti-skid manifold. The input pressure to the ASM was also measured for comparison. For both valves the anti-skid manifold was installed but no anti-skid control was provided.

The test was performed 7 times on DBCV, S/N 444076. The first two tests yielded similar results, the data from the second test is shown in Plot 1. As the input angle increases from zero there is no response from the valves until about 11 degrees when the C and D brakes exhibit a step response up to about the input pressure level. Slightly less than 1 degree of additional input yields a step response of the A and B brakes up to about the input pressure level. As the DBCV is actuated to its full travel and back to zero the response from all four brakes is smooth and matches the input pressure in slope. The A and B brakes exhibit pressures less than the input pressure with the B brake exhibiting more pressure loss. The A brake pressure loss is more pronounced below about 1500 psi. The C and D brake response matches the input pressure very well.

The test 3 results are shown in Plot 2. Again, there is a step response of all four brakes in the 12° to 13° input range but no distinct separation between brake pairs. The A and B brakes exhibit lower pressures than the input pressure and the A brake pressure loss is more than the previous tests. The A brake pressure loss is more pronounced below about 2000 psi. The B brake exhibits a cutoff with a maximum pressure of only 2200 psi attained.

The results from tests 4 – 7 were similar and thus only the results from test 4 are shown in Plot 3. There is no step response of the brakes in these tests. The C and D brakes exhibit a response that matches the input pressure very well through the entire range. The A and B brakes exhibit a response that is less in magnitude and the B brake exhibits a cutoff such that the maximum pressure attained is about 2300 psi. The A brake pressure difference is much more pronounced below about 200 psi.

The same test was performed 2 times on DBCV, S/N 438942. The results of the first test are shown in Plot 4. As the input angle increases from zero there is no response from the brakes until about 13° when the C and D brake pressure exhibits a step response up to about the input pressure. Slightly more that 1° later the A and B brakes exhibit a similar step response up to values less that the input pressure. From the step up to full travel and back to zero the C and D brakes match the input pressure very well. The A brake response is less that the input pressure below about 2300 psi but matches very well above. The B brake response has a higher magnitude of difference that the A brake and only attains a maximum pressure of about 2300 psi.

The results from test 2 on DBCV, S/N 43892, are shown in Plot 5. The results for all 4 brakes are smooth with no step response and the C and D brakes match very well with the input pressure. The A and B brakes exhibit responses less than the input pressure similar to test 1 and the B brake only attains a maximum of about 2300 psi.

The second phase of testing on the DBCV's involved rapid manual activation of the valves such that the output pressure was about 1/4, 1/2, 3/4, and full system pressure while measuring the pressure recorded at the four brakes as a function of time. The various pressures were obtained by utilizing a stop on the input arm such that the required output pressure was obtained. The test was performed with different configurations of DBCV's, ASM's, and line length configurations as noted below.

Setup 1 – DBCV (S/N 444076), ASM (S/N 114), Left side short lines
Setup 2 – DBCV (S/N 444076), ASM (S/N 114), Left side long lines
Setup 3 – DBCV (S/N 444076), ASM (S/N 113), Left side long lines
Setup 4 – DBCV (S/N 438942), ASM (S/N 114), Left side short lines

The results from setups 1, 2, and 4 were very similar and had a marked difference from the results from setup 3. Only the results from setups 2 and 3 are presented below.

Plots 6 and 7 show the test results from setups 2 and 3, respectively, with the brake valve actuated such that the output pressure was about 500-600 psi. In all of the results there is an initial lag between the DBCV output pressure and the response measured at the brakes. With setup 2 shown in plot 6 and setups 1 and 4 not shown there is a lag in the response of the A and B brakes and more oscillation of the response than in the C and D brakes. The A and B brakes also only rise to about 60%-70% of the DBCV output pressure. The C and D brake responses are very similar and match the DBCV output pressure well. The response shown in plot 7 shows that all four brakes respond at about the same time and match the DBCV output pressure in slope. The response at the brakes yields between 75% and 85% of the DBCV output pressure. The A and B brakes exhibit more oscillation in the response than the C and D brakes.

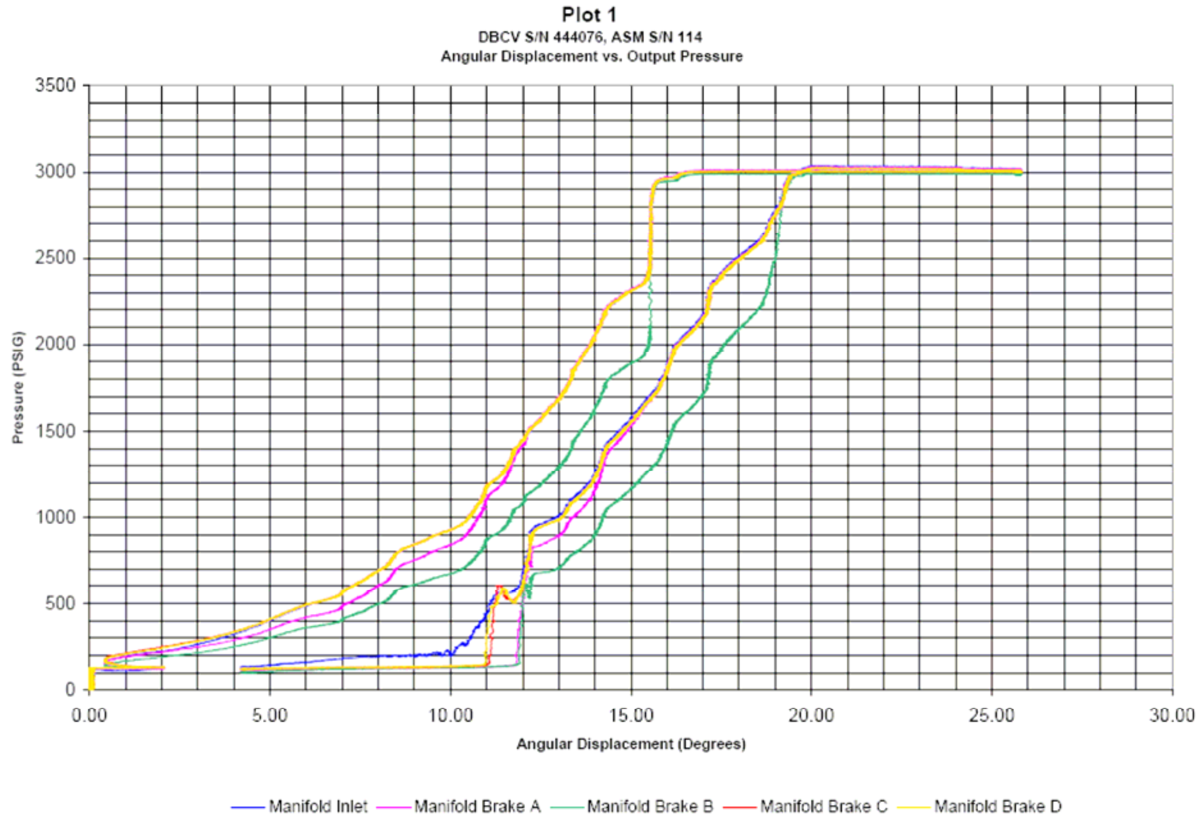
Plots 8 and 9 show the results from setups 2 and 3, respectively, with the brake valve actuated such that the output pressure was about 1100 psi. In plot 8, all four brake pressures respond at about the same time but the A and B brakes only attain 65%-75% of the DBCV output pressure. The A and B brakes again exhibit more oscillation in their response than the C and D brakes. The results in plot 9 show all four brakes responding at the same time and reaching a peak between 88%-93% of DBCV output pressure. The responses all follow the DBCV output pressure well with the exception of the initial lag in the response typical of all the results.

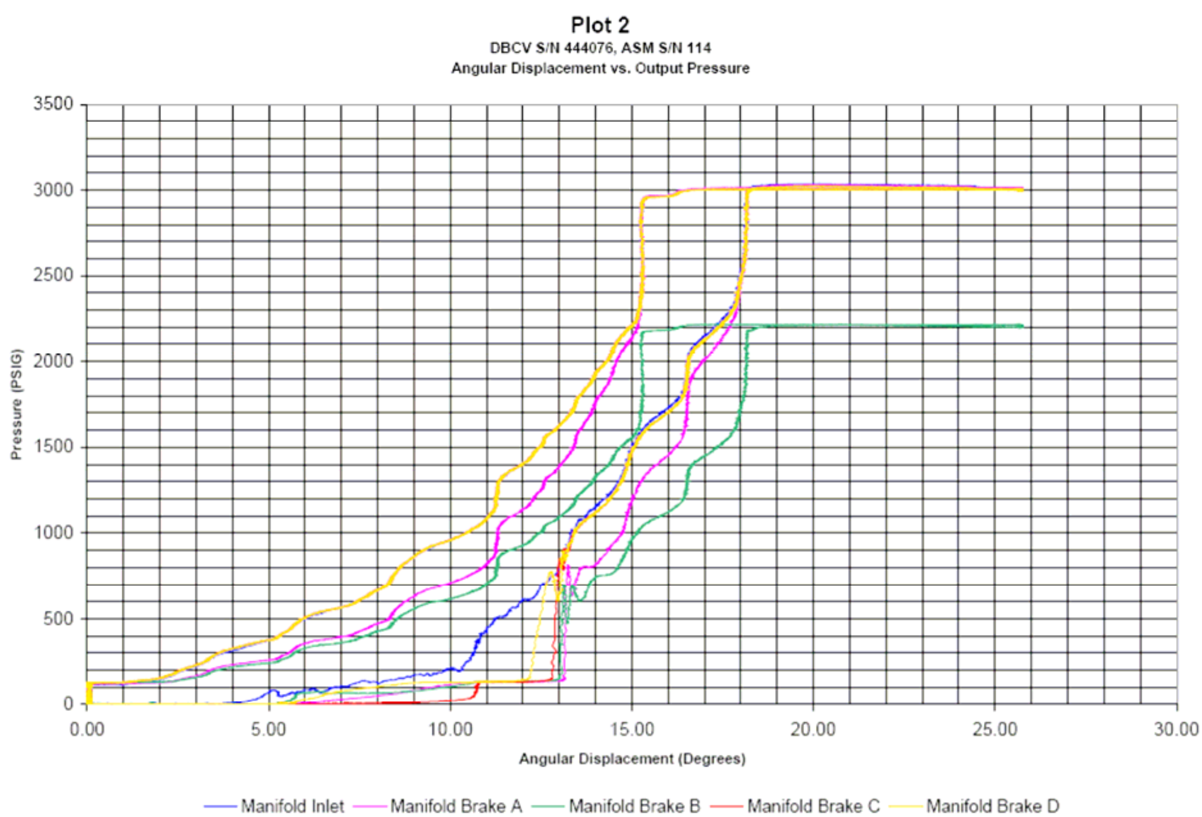
Plots 10 and 11 show the test results from setups 2 and 3, respectively, with the brake valve actuated such that the output pressure was about 2400 psi and 1900 psi, respectively. In plot 10, all four brake pressures respond at about the same time and match the DBCV output pressure quite well with the exception of the B brake. The B brake only attains about 70% of the DBCV output pressure. There again is more oscillation in the A and B response. The results from setups 1 and 4 look very similar to those shown in plot 10 except the A brake pressure does not attain the DBCV output pressure. The results in plot 11 agree very well with the DBCV output pressure after the initial lag. There is a little more oscillation in the A and B response. All four valves reach the DBCV output pressure.

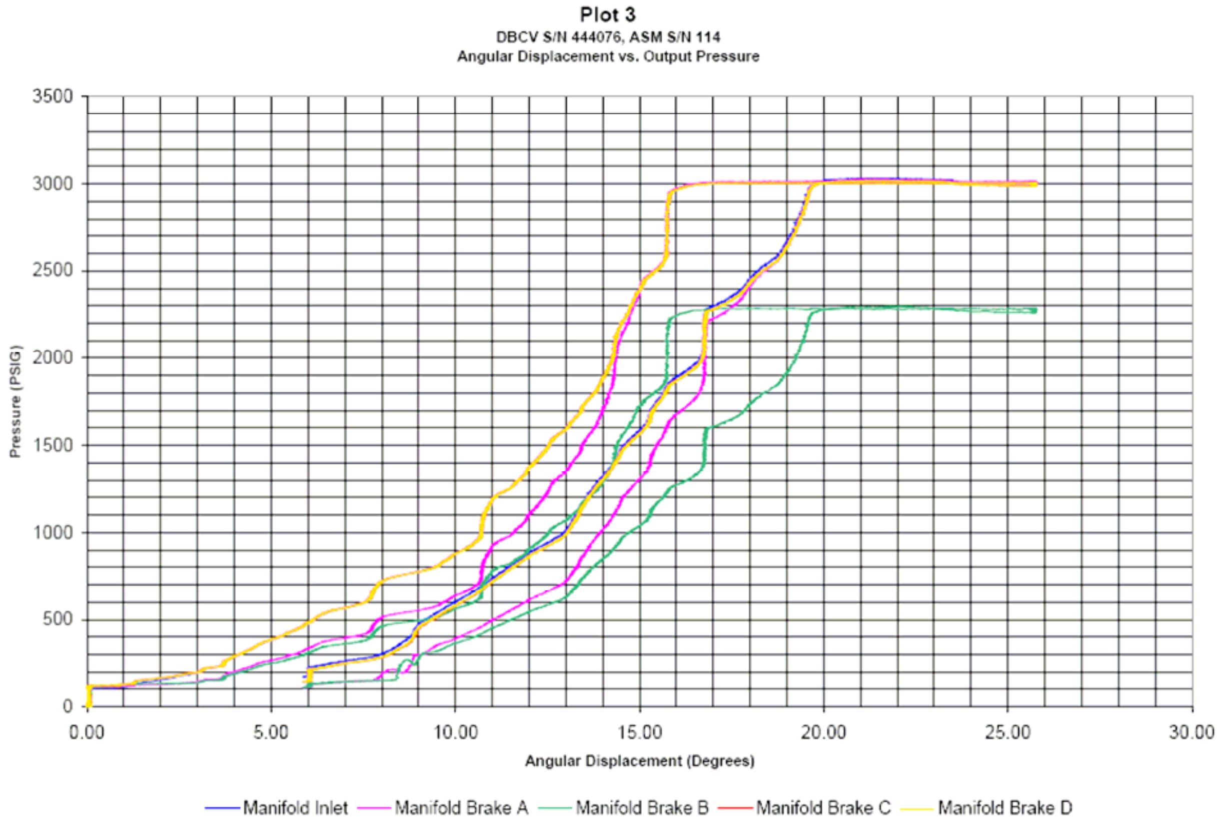
Plots 12 and 13 show the results from setup 2 and 3, respectively, with the brake valve actuated such that the output pressure was full system pressure. In plot 12, all four brake pressures respond at about the same time and match the DBCV output pressure with the exception of the B brake. The B brake only attains about 77% of the DBCV output pressure. Again, there is more oscillation in the A and B brake response. The results in plot 13 agree very well with the DBCV output pressure after the initial lag. The A and B response exhibits slightly more oscillation that the C and D response.

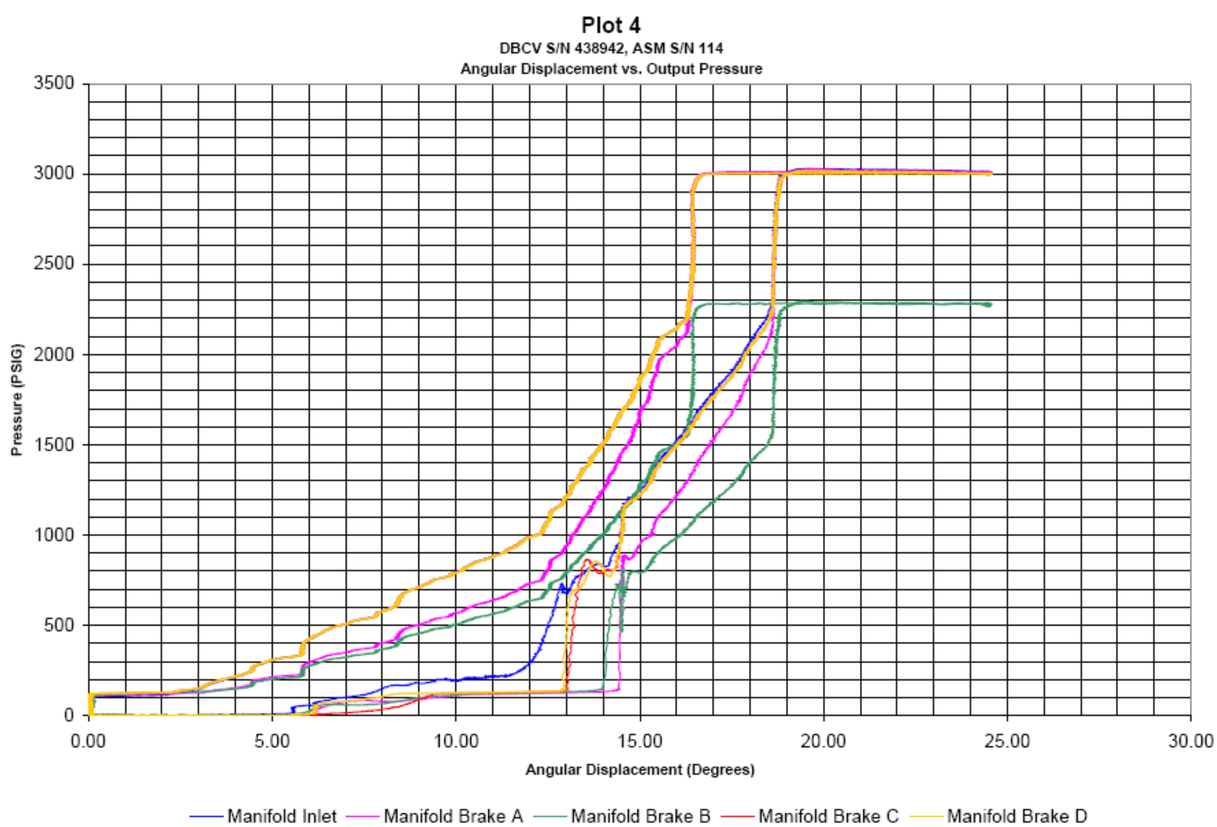
The second phase of testing involved installation of the DBCV's and ASM's in the MD-10-10F carbon brake simulation fixture and utilizing a computer program to simulate an actual landing while measuring the anti-skid response. Upon initiation of the test procedure, excessive vibration and noise from the ASM, S/N 114, was noted. Examination of the data from the C and D anti-skid valves showed that their pressure control was getting worse with each run leading to a total loss of control. ASM, S/N 113, was installed in the fixture and again excessive noise and vibration was noted. The D anti-skid valve was not performing correctly like the C and D valves in S/N 114. It was later determined that the electrical connection to the D valve was missed during the change of the valves. Due to time constraints, a third new ASM was installed in the fixture and the simulation was run with satisfactory results. The results from this testing will not be presented since they do not apply to the accident airplane hardware. Likewise, the effects of cooling of the brake fluid were only performed with the new ASM due to the problems encountered with the accident airplane ASM's. These results are not presented in this report.

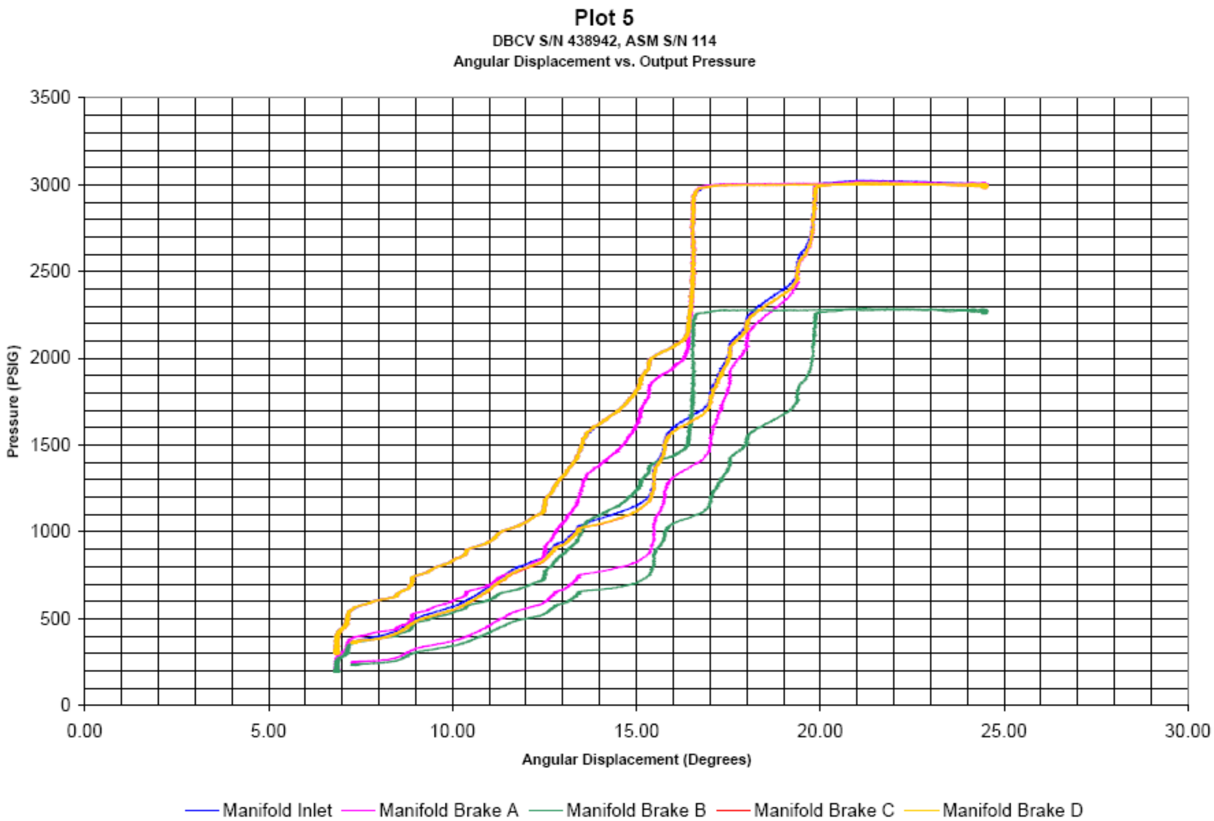
ASM, S/N 114, was removed and subjected to the acceptance test procedure. The results from the C and D ports exhibited no pressure control. The valves acted like solenoid (on or off) valves instead of pressure control valves. The C and D valves were disassembled for examination. The flapper-armatures exhibited cracks at the upper braze joint between the flexure and the armature. The A and B valves were also disassembled for comparison. The pressure nozzle on the A port exhibited heavy damage (flattening). The B port exhibited normal wear for a valve of its age.

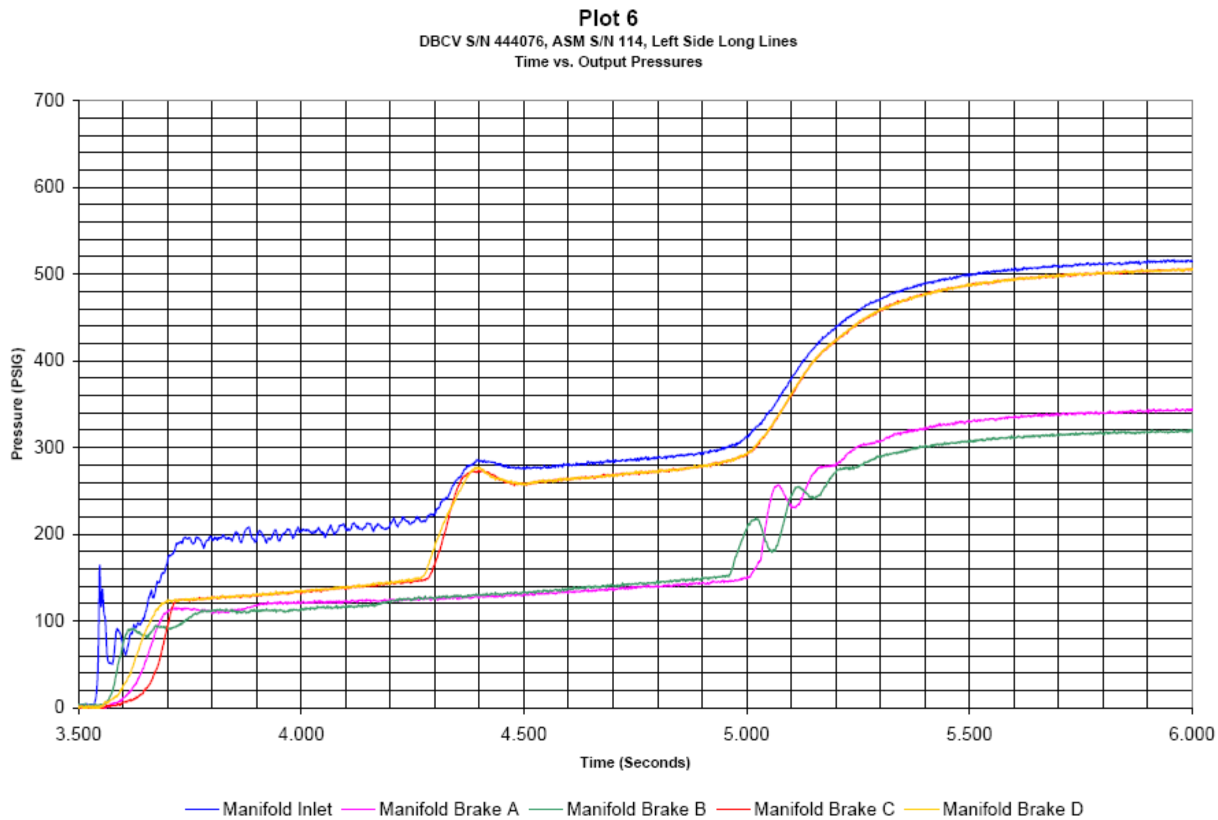

Plot 1
DBCV S/N 444076, ASM S/N 114
Angular Displacement vs. Output Pressure
Pressure (PSIG)
3500
3000
2500
2000
1500
1000
500
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Angular Displacement (Degrees)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D

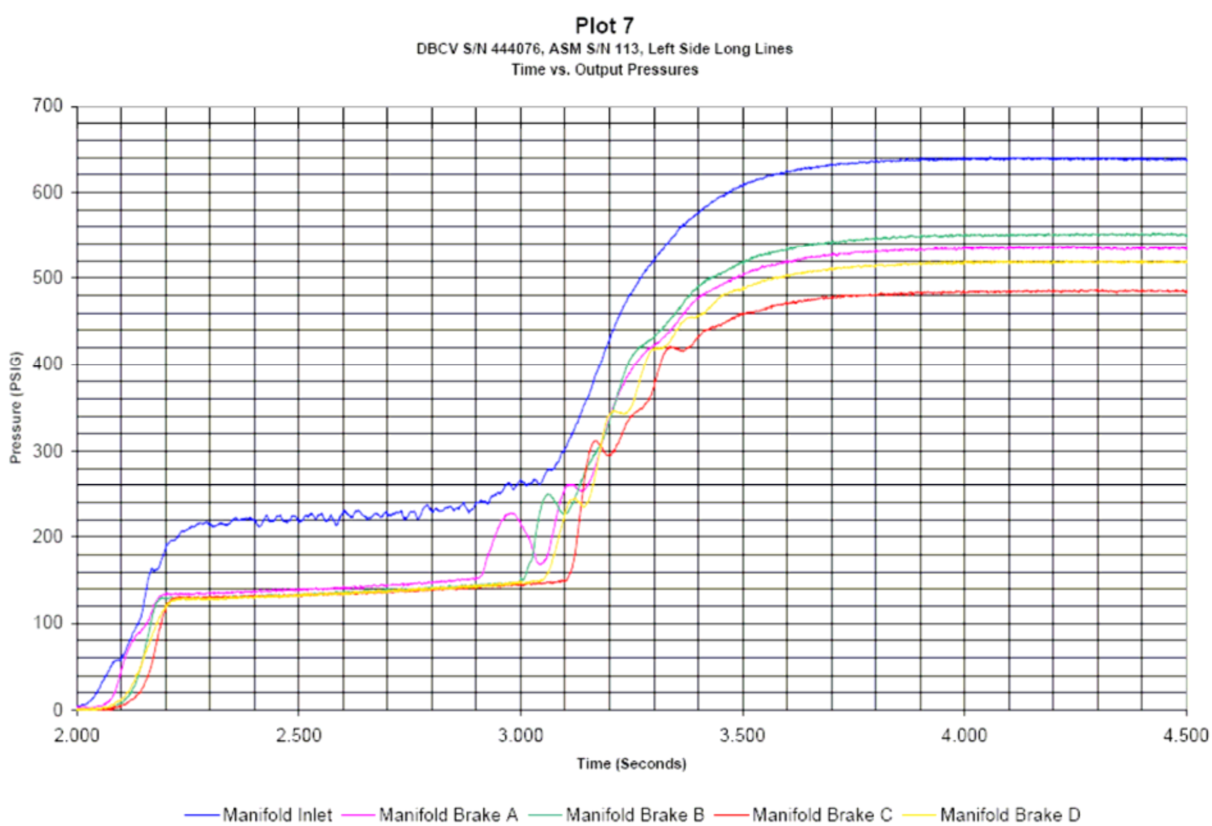

Plot 2
DBCV S/N 444076, ASM S/N 114
Angular Displacement vs. Output Pressure
Pressure (PSIG)
3500
3000
2500
2000
1500
1000
500
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Angular Displacement (Degrees)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D

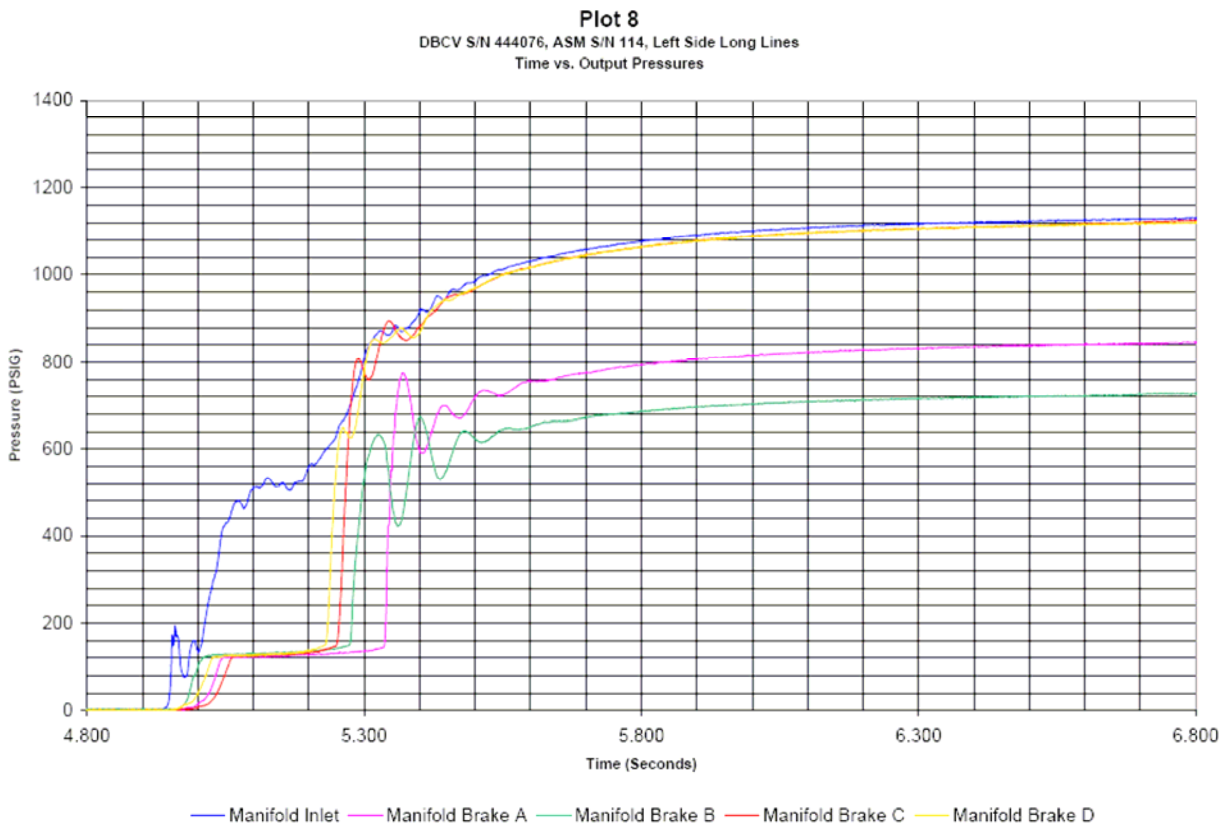

Plot 3
DBCV S/N 444076, ASM S/N 114
Angular Displacement vs. Output Pressure
Pressure (PSIG)
Angular Displacement (Degrees)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D

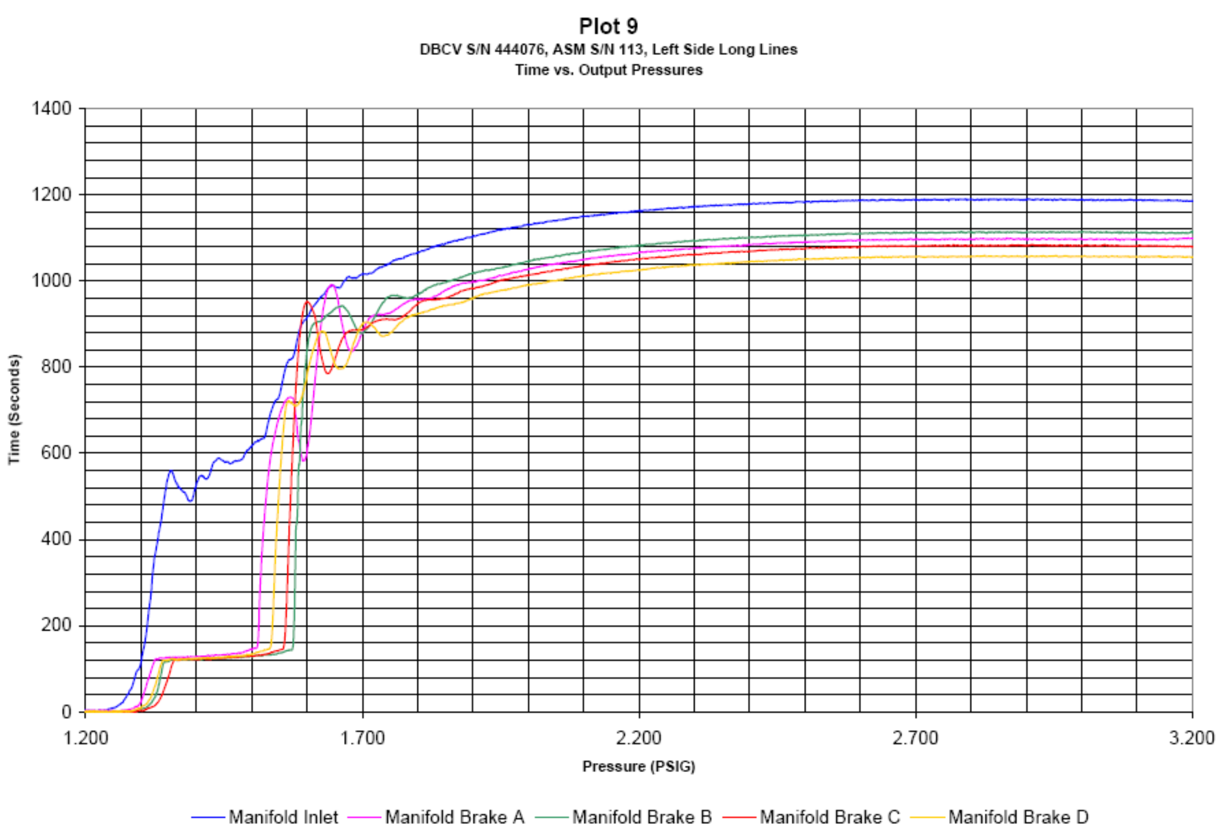

Plot 4
DBCV S/N 438942, ASM S/N 114
Angular Displacement vs. Output Pressure
Pressure (PSIG)
Angular Displacement (Degrees)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D

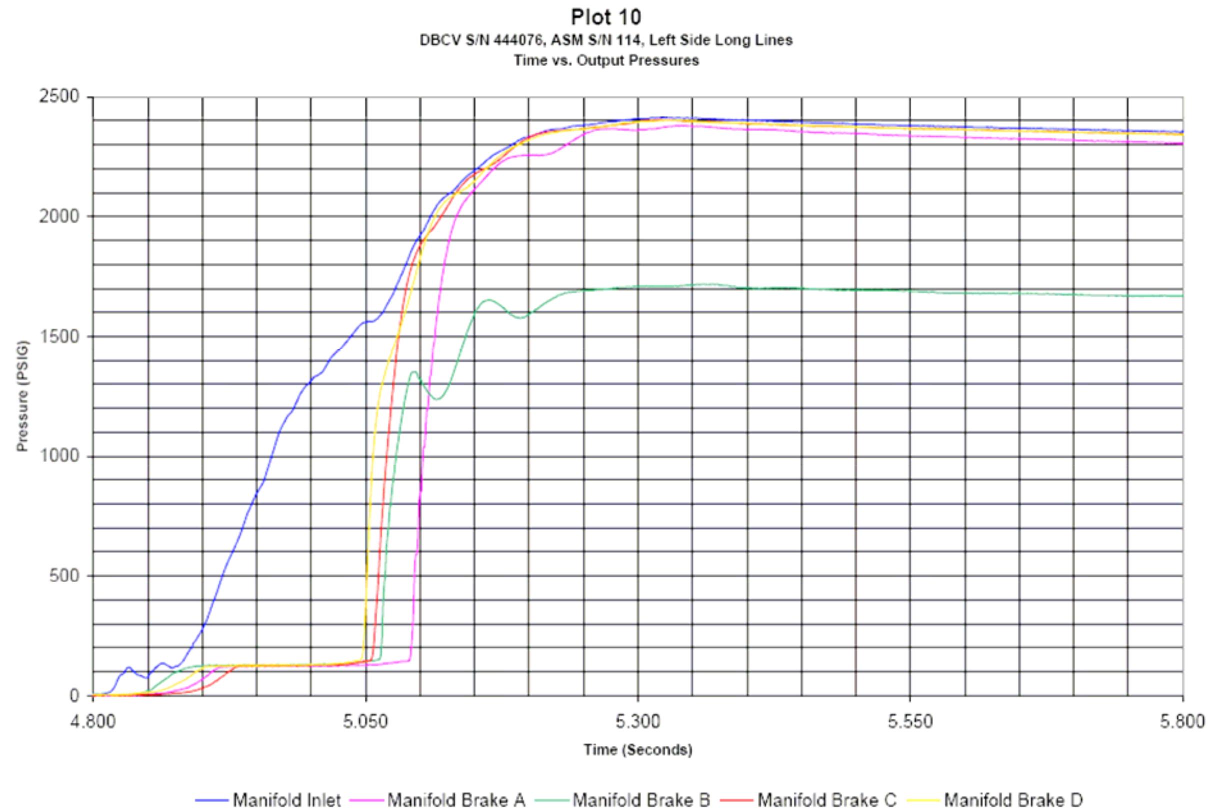

Plot 5
DBCV S/N 438942, ASM S/N 114
Angular Displacement vs. Output Pressure
Pressure (PSIG)
3500
3000
2500
2000
1500
1000
500
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Angular Displacement (Degrees)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D

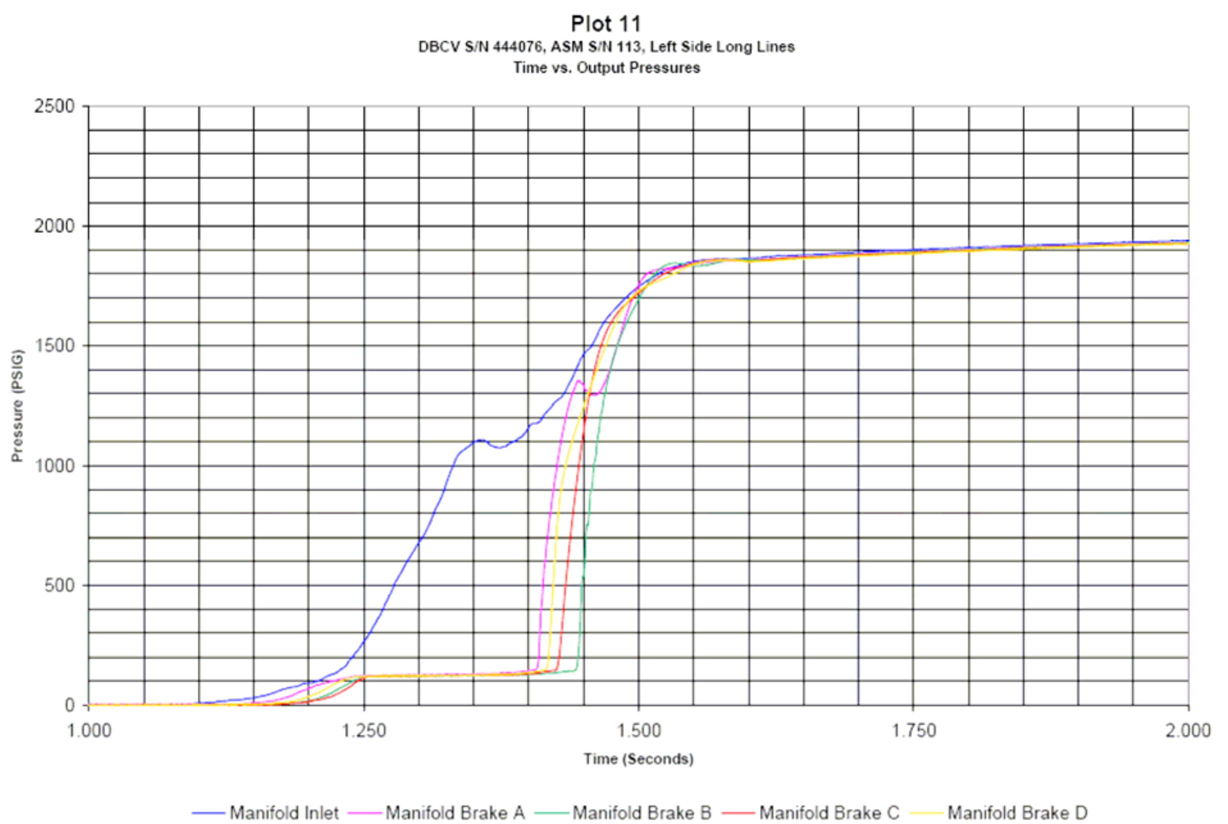

Plot 6
DBCV S/N 444076, ASM S/N 114, Left Side Long Lines
Time vs. Output Pressures
Pressure (PSIG)
700
600
500
400
300
200
100
0
3.500
4.000
4.500
5.000
5.500
6.000
Time (Seconds)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D

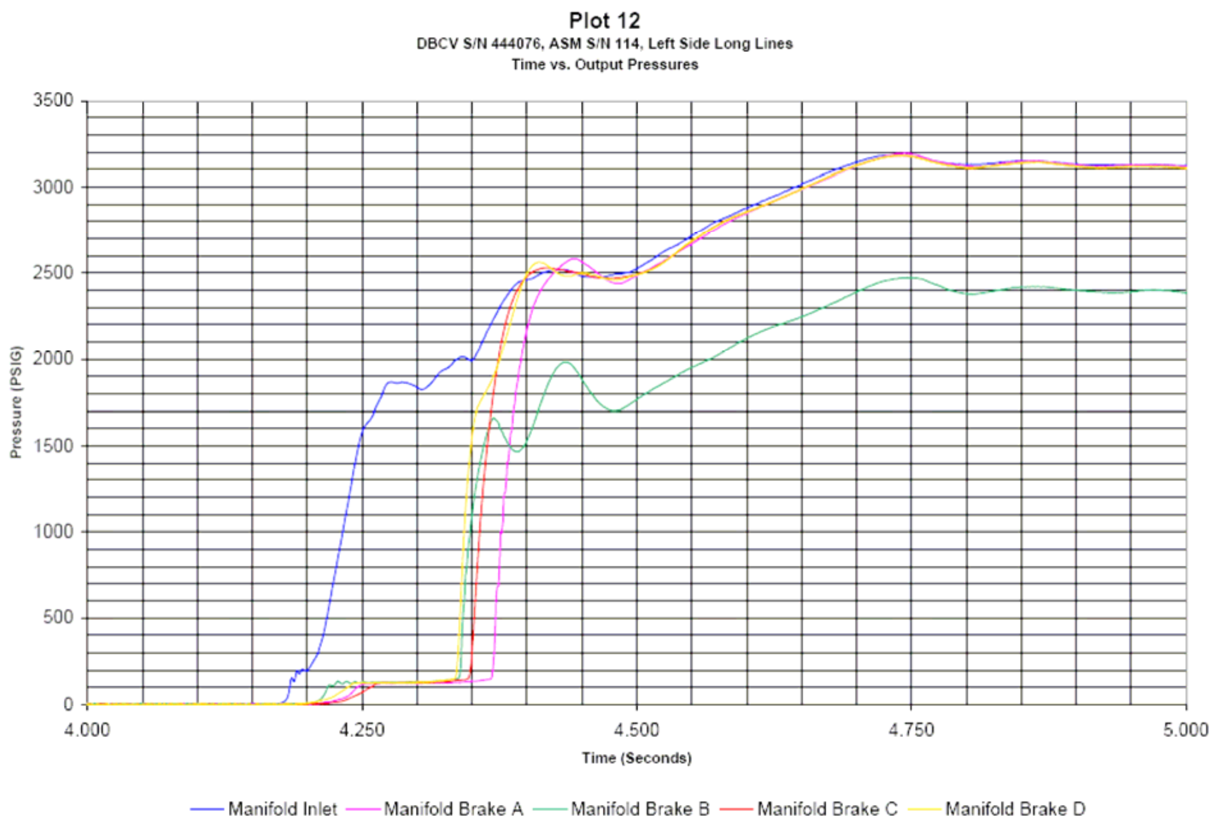

Plot 7
DBCV S/N 444076, ASM S/N 113, Left Side Long Lines
Time vs. Output Pressures
Pressure (PSIG)
700
600
500
400
300
200
100
0
2.000
2.500
3.000
3.500
4.000
4.500
Time (Seconds)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D

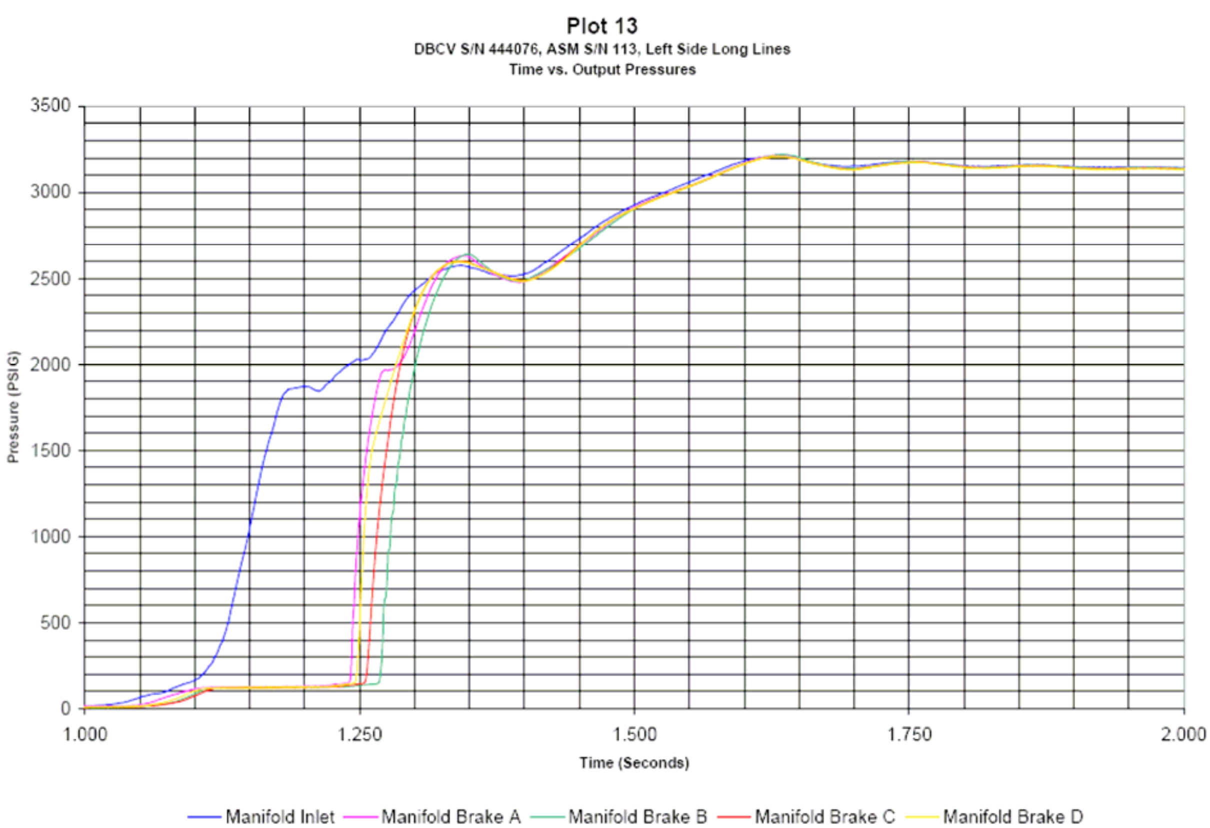

Plot 8
DBCV S/N 444076, ASM S/N 114, Left Side Long Lines
Time vs. Output Pressures
Pressure (PSIG)
Time (Seconds)
1400
1200
1000
800
600
400
200
0
4.800
5.300
5.800
6.300
6.800
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D


Plot 9
DBCV S/N 444076, ASM S/N 113, Left Side Long Lines
Time vs. Output Pressures
Time (Seconds)
Pressure (PSIG)
1400
1200
1000
800
600
400
200
0
1.200
1.700
2.200
2.700
3.200
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D


Plot 10
DBCV S/N 444076, ASM S/N 114, Left Side Long Lines
Time vs. Output Pressures
Pressure (PSIG)
2500
2000
1500
1000
500
0
4.800
5.050
5.300
5.550
5.800
Time (Seconds)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D


Plot 11
DBCV S/N 444076, ASM S/N 113, Left Side Long Lines
Time vs. Output Pressures
Pressure (PSIG)
2500
2000
1500
1000
500
0
1.000
1.250
1.500
1.750
2.000
Time (Seconds)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D


Plot 12
DBCV S/N 444076, ASM S/N 114, Left Side Long Lines
Time vs. Output Pressures
Pressure (PSIG)
3500
3000
2500
2000
1500
1000
500
0
4.000
4.250
4.500
4.750
5.000
Time (Seconds)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D


Plot 13
DBCV S/N 444076, ASM S/N 113, Left Side Long Lines
Time vs. Output Pressures
Pressure (PSIG)
3500
3000
2500
2000
1500
1000
500
0
1.000
1.250
1.500
1.750
2.000
Time (Seconds)
Manifold Inlet
Manifold Brake A
Manifold Brake B
Manifold Brake C
Manifold Brake D