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Test conducted at VRTC on the Bosch Brakes (ZOPS).
2001 Monaco Holiday Rambler Ambassador Motorhome

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INTERIM REPORT -- VRTC-DCD2037 (EA02-034)

Tests of the Bosch Brakes (ZOPS) on a 2001 Monaco Holiday Rambler Ambassador Motorhome

1.0 INTRODUCTION

This test program was performed at the Vehicle Research and Test Center (VRTC) in response to a request by the Office of Defects Investigation (ODI), National Highway Traffic Safety Administration (NHTSA). The ODI has received complaints alleging brake overheating on the Bosch "Zero-Offset Pin Slide" (ZOPS, aka International Diamondlife) caliper brake system on various vehicles. Many complainants have alleged that these brakes apply normally, and then fail to fully release, resulting in overheated wheel-ends and fires on various vehicles, including school buses.

2.0 BACKGROUND DISCUSSION

The primary objective of this portion of the test program was to document the condition and performance of the ZOPS brake system on a Monaco Holiday Rambler Ambassador motorhome that had just been repurchased by Monaco. An additional front axle that had been previously replaced under warranty by Monaco was also tested later on the motorhome.

3.0 TEST VEHICLE AND A WARRANTY-REPLACEMENT AXLE

The test vehicle, designated MH1, was a 2001 Monaco Holiday Rambler Ambassador with VIN 1RF12041012012312 and the odometer reading was 9,946 miles at the start of testing. The weight placard on the 36-ft long vehicle listed 10,500 lb for the front Gross Axle Weight Rating (GAWR), 15,500 lb for the rear GAWR, and 26,000 lb for the Gross Vehicle Weight Rating (GVWR). A placard on the front axle identified it as a Westport Model No. F5W-1200. The vehicle had been repurchased by Monaco after multiple thermal events were reported on the rear axle. The last reported event was a brake fire on the right rear wheel-end. A photograph of the vehicle is shown in Figure 1 in the Appendix. All tables and figures for this report are presented in the Appendix.

The warranty-replacement front axle, designated AXL1, procured from Monaco, was reportedly replaced under warranty because owner had reported a left front brake fire. Subsequently, the left rotor temperature was measured, with a handheld optical pyrometer, at the dealership at over 1,000°F. This warranty-replacement axle had been removed from another 2001 Monaco Holiday Rambler Ambassador with VIN 1RF12041512012855 and the odometer reading was reported to have been 11,891 miles. The axle was stored by Monaco for approximately three months before it was procured by the VRTC. A placard on the axle identified it as a Westport Model No. F5W-1200. A photograph of the axle, as received by VRTC, is shown in Figure 2.

4.0 TEST EQUIPMENT AND PROCEDURES

The instrumentation package used to record the performance of each of the four wheel-ends included sensors for brake line pressure (inboard of the flexible brake hose), the inner brake pad temperature (thermocouples installed from the edge so as to avoid disturbing the "as received" brake condition), and the brake fluid temperature inside the caliper (probe inserted through the bleeder valve). The vehicle stopping distance, vehicle speed and deceleration, and brake pedal force and travel were also monitored. Videotape cameras, mounted near the centerline of the vehicle looking outboard, were used to record events at each wheel-end. The front axle views of the caliper and rotor were slightly restricted by the front axle, and the rear axle views of the caliper and rotor were significantly restricted by the suspension trailing arm and splash shields. A halon fire-suppression system was built and installed on the motorhome with two nozzles positioned at each caliper. This system included a backup halon gas cylinder for longer duration fire suppression (if needed) and a control panel that allowed fire suppression at either a single wheel or all wheels simultaneously. The equipment used for the instrumentation, the videotape, and the fire suppression systems are listed in Table 1 and shown in Figures 3 through 11. Note: the Parker Corp. solenoids, selected for the fire suppression system, were later found to be incompatible with halon gas and are not recommended.

The first test was conducted on the Skid Pad at the Transportation Research Center (TRC). The Skid Pad has a one-mile straightaway for brake testing and loops at each end, as shown in Figure 12. The driver performed a stop from 40 mph at a deceleration rate of 0.3 g, and then resumed driving at 40 mph with repeated 0.3-g stops and cool-down periods sufficient to maintain post-stop pad temperatures of 200°F, then 300°F, then 400°F, and finally 500°F. In general, three stops were made at each temperature level before targeting the next post-stop temperature.

Another test conducted was similar, except the vehicle was snubbed from 40 mph to 15 mph at a 0.3-g deceleration rate. Additional tests were conducted on the Vehicle Dynamics Area (VDA) and High Speed Test Track (HSTT) when necessary to accommodate TRC scheduling conflicts.

As a diagnostic tool, the torque required to rotate each wheel was measured after the vehicle was lifted from the ground. A bound caliper would be indicated by a high turning torque reading. The torque required to cause the wheels to start moving and to maintain the spinning or running torque were found. This torque on the wheel was measured by installing a torque wrench onto a wheel lug nut with the longitudinal axis of the torque wrench handle aligned as closely as possible with the center of the wheel. Then a correction factor was applied to convert the center of rotation from the lug nut position to the center of the wheel, as shown below.

$$Ta = Tm[(A+L)/L]$$

where Ta = actual wheel turning torque
Tm = measured wheel torque with torque wrench on lug stud and radially aligned through center of wheel
A = distance from center of wheel to lug stud
L = distance from center of torque wrench handgrip to center of the socket adapter at the lug site

5.0 INSPECTION AND TEST RESULTS

The vehicle had been repurchased by Monaco and the VRTC took immediate possession of the vehicle from the dealership in Alabama. No work had been performed on the vehicle since the reported brake fire at the right rear wheel-end. The vehicle appeared to be in good condition and the brakes operated normally when the vehicle was received, except the ABS-warning lamp was illuminated. The measured weights were 7,840 lb on the front axle, 14,040 lb on the rear axle, and 21,880 lb for the total weight.

As soon as the vehicle was lifted in the shop, the wheels were turned by hand and the force required to rotate each wheel seemed reasonable. The brake components appeared to be in good working order, except the right rear ABS wheel-speed sensor (the location of the reported fire) was found to be severely melted and had fallen out of the interference-fit socket, as shown in Figure 13. The sensor on the Wabco ABS was not repaired until later in the test program. Tests using the Markey Vapor Lock Indicator found the brake fluid boiling points were 375°F to 398°F at the wheel-ends and 425°F at the master cylinder reservoir, indicating the brake fluid was relatively new. Once the instrumentation was installed, the brake system was thoroughly inspected for "trapped" brake line pressure that could cause a dragging brake. The items checked included fluid exchange malfunctions between the master cylinder and reservoir, binding at the brake pedal linkage, overboost in the hydroboost system, swelling of ABS internal seals, and restrictions in the metal brake lines or flexible rubber hoses.

The torque required to rotate each wheel on MH1 was measured just before the first driving test. After three spike applications on the brake pedal (with the engine running), the static breakaway torques required to rotate the wheels were determined to be 12/12 ft-lb (left/right front) and 51/26 ft-lb (left/right rear). The dynamic (continuously running) torques were 7/7 ft-lb (left/right front) and 40/30 ft-lb (left/right rear). The increased torque required was expected on the rear axle due to the differential and drivetrain drag.

During the first test, the weather conditions included an ambient temperature of 33°F, a 5-mph wind from the northeast, 87% humidity, and sleet, snow, and rain. The test surfaces were wet, but clear of ice and snow, except for portions of the north and south loops of the Skid Pad, where braking did not occur. After 20 normal 0.3-g stops, with intentionally increasing post-stop temperatures, the post-stop temperatures of the inner-brake pads were 526/526/585/518°F (LF/RF/LR/RR). At this point, the goal was a 500°F post-stop brake lining temperature. The testing had to be stopped for 5 minutes to change the videotapes and wipe the moisture from the camera box lenses. After resuming the brake applications, the left rear wheel temperature was noticeably deviating from the other wheels (510/520/**650**/520°F) after four stops. For the next 4 minutes, the vehicle was driven, without braking, between 20 mph in the loops and 40 mph on the straightaways and the rotor started to glow red, as shown in Figure 14. The temperatures dropped on three of the wheels, but continued to climb at the left rear wheel (398/359/**1,095**/430°F). At this point, the brakes were catching on fire, as shown in the videotape submitted with this report. The driver had no indication of any problems. Throughout the event, the vehicle did not yaw, exhibit noticeable drag during acceleration, and there was no smoke or odor noted in the passenger compartment.

The vehicle was then stopped for 1 minute and all four wheel temperatures started to drop. As the vehicle was driven away, a wheel fire flamed up as shown in Figure 15. Note: In the upper view of the figure, the camera auto-iris circuitry had malfunctioned so the picture is relatively dark. The camera was replaced before the next test. The lower view in Figure 15, taken using from the replacement camera, shows the same field of view for comparison. The trailing arm is in the right bottom corner, the rear axle is across the left side, and one-half of the caliper is near the center of the picture. The video images are clearer than the picture transferred from the video for Figure 15.

The vehicle was driven a short distance and the temperature on the left rear wheel continued to rise during this portion of the test (368/328/**1,330**/398°F). Each time the vehicle stopped, all of the brake temperatures cooled down. Each time the vehicle started moving again, the left rear wheel fire would flare up. The data collection was normally retriggered every 10 minutes, but at this point, retriggering was inadvertently delayed for a 4-minute period. During this period, the real-time readout was pegged at 1,400°F, the limit of the instrumentation. The brake fluid temperature in the calipers had been between 70°F and 80°F. Each time the vehicle was stopped, the left rear wheel area would heat-soak, and the brake fluid temperature in the left rear caliper would rise. At this point, the fluid temperature at the left rear had risen to 169°F. The highest brake fluid temperatures recorded were 86/64/306/92°F, which may possibly cause boiling in a vehicle with hydroscopically-aged brake fluid. However, the brake fluid boiling point of this vehicle was about 400°F. While pulling away from a stop during the 4-minute period of data loss, a "pop" was heard from the left rear wheel area and the vehicle rocked forward slightly. This indicated that this piston probably expanded thermally and seized temporarily in the bore. The high thermal readings began to diminish, even after continuing the braking and driving sequence. When it was determined that the thermal event could not be repeated, it was too late to perform the planned on-track diagnostic tests to determine which subcomponent had failed to operate normally.

More information about this test is available from the test instrumentation. The individual 10-minute data collection files are shown in Figures 16 through 24. A composite plot of the four 10-minute data files during the thermal event is shown in Figure 25. The composite image shows the inner brake lining temperatures stepping upward with the initial testing, until the temperature of the left rear (green trace) deviates into an abnormal thermal event. The wide blank space is the area where the data collection system had not been triggered in a timely manner and where the lining temperature reached the peak (limit of data channel) of 1,400°F. There was no evidence of residual brake line pressures at any time during this test.

The original front axle, which did not demonstrate any abnormal activity during the previous test, was removed so that warranty-replacement axle, AXL1, could be installed on the motorhome for the next test. The AXL1 axle was an exact match for the original front axle and there were no problems during the installation. The axle appeared to be in good shape, with no obviously melted components, but the left rotor surface was corroded. The disc brake on the left side was where the owner reported a fire had occurred. The wheel torque required to rotate the wheels on MH1 equipped with AXL1 were measured just before the subsequent driving test. After three spike applications to the brake pedal, the static breakaway torques required to rotate the wheels were determined to be 20/12 ft-lb (left/right front) and 46-51 ft-lb (left/right rear). The dynamic (continuously running) torques were 15/10 ft-lb (left/right front) and 36/41 ft-lb (left/right rear). The increased torque required was expected on the rear axle due to the differential and drivetrain drag.

During the second test on MH1, the weather conditions included an ambient temperature of 29°F, a 10 mph wind from the east, 68% humidity, and cloudy. The test surfaces were wet, but clear of ice and snow, except for portions of the north and south loops of the Vehicle Dynamics Area (VDA), where braking did not occur. After 14 normal 0.3-g stops with intentionally increasing post-stop temperatures, the post-stop temperatures of the inner brake pads were 450/629/603/578°F. A composite plot of five 10-minute files during the time of the abnormal thermal event is shown in Figure 26. After the goal of 500°F post-stop brake lining temperatures was reached, the testing was stopped for 4 minutes to change the videotapes and wipe the moisture from the camera box lenses. As the vehicle was driven away from this stop, the driver noticed a slight pull to the right. One minute later, the right front brake-lining temperature was increasing noticeably without the brakes being applied (342/**552**/425/427°F). The vehicle was driven without braking and 3 minutes later, although the three other wheel-end temperatures were dropping, the right front temperature was rising (291/**755**/390/403°F). At this time, the rotor started to glow red, as shown in Figure 27. The driver still noticed a slight steering pull to the right and a hot-brake odor was entering the passenger compartment from the area of the right front door. The vehicle was driven without braking for 8 minutes at 40 mph (slower for the loops). The right front brake temperature exceeded 1,000°F (193/**1,016**/322/348°F) and then started to drop off. The vehicle was stopped for four more minutes and upon resuming driving, without brake applications, the right front brake temperature started to rise again (161/**1,262**/280/311°F). The brake fluid temperature in the right front caliper reached 217°F. Similar to the first test, there was no evidence of residual brake line pressures at any time during this test.

The test was terminated so that the planned on-track diagnostic component checks could be performed. The vehicle was driven 500 ft away from the VDA test route and the frame was lifted to remove the vehicle weight from the right front wheel. The breakaway torque required to rotate the wheel was 140 ft-lb (at the start of the test it was 12 ft-lb). The wheel was removed and locking pliers (Vise-Grips) were clamped on the brake pad backing plates (at the abutment ears) and used to attempt to "rattle" the inner and outer brake pads. If only the outer pad was tight, a slide pin problem could be indicated; and if both pads were tight, a piston problem could be indicated. In this case, both pads were tight. The slide-pin-mounting bolts were removed but the caliper was still tight on the rotor. The caliper was removed from the rotor and a flat metal bar was laid across the dual pistons. Then a C-clamp was used to attempt pushing the pistons back into the caliper housing, but the pistons would not move. Next, a 2-1/2 inch wooden block was laid in place of the rotor and pads and the brake pedal was slowly applied by hand. The leading piston was found to be immobile so the brakes were reassembled and the vehicle was driven back to the VRTC. It should be noted that some of the features of the Bosch ZOH-T design to improve the ZOPS caliper were added to prevent piston bore binding. The next morning when the brake components were examined, the caliper operated normally again.

The right front brake was replaced with new parts and five more tests (Dec 18-31) were conducted as shown in Table 2. The brake system worked as expected on the remaining tests.

The testing was followed by a systematic teardown to the brake component level. The individual components were stored in sealed plastic containers with desiccant for further testing. The brake equipment from each wheel-end was examined, the attachment of that component documented, and photographed. The condition of each component and the integrity of the attachment system is listed in Table 3. The photographs showing the condition of the brake equipment at each wheel-end are shown in Figures 28 through 37.

6.0 FINDINGS

The subject motorhome and components for this program included a 2001 Monaco Holiday Rambler Ambassador and an additional front axle previously replaced by Monaco under a warranty claim.

1) Upon initial inspection, the motorhome and brake components appeared to be in good working order, except the right rear ABS sensor was found melted and out of the interference-fit socket (a fire had been reported at this wheel-end), thus causing the ABS warning light to illuminate. The front and rear axle wheels could be turned with reasonable effort, indicating no abnormal drag.
2) A dragging brake could be caused by trapped brake line pressures at the wheel-ends. A thorough inspection of the brake system revealed none of the following possible problems: fluid exchange malfunctions between the master cylinder and reservoir, binding at the brake pedal linkage, overboost problem in the hydroboost system, swelling of ABS internal seals, and restrictions in the metal brake lines or flexible rubber hoses. No evidence of residual brake line pressures was indicated by the instrumentation at any time during these tests.
3) The first test on the "as received" motorhome resulted in a wheel-end fire at the left rear brake after a series of 0.3-g stops, followed by driving without braking at 20 to 40 mph. The fire lasted for 15 minutes before diminishing after a "pop" sound was heard from the left rear wheel area and a "rock-forward" of the vehicle was noted. This indicated that this piston probably expanded thermally and seized temporarily in the bore. The inner brake pad lining temperature exceeded 1,400°F and the brake fluid temperature at that wheel rose to 306°F.

Throughout the event, the vehicle did not yaw or exhibit noticeable drag during acceleration, and there was no smoke or odor noted in the passenger compartment.

4) The second test was conducted after installing a front axle previously replaced by Monaco under warranty. This test also resulted in an abnormal thermal event after a series of 0.3-g stops, followed by driving without braking at 20 to 40 mph. The right front rotor glowed red for approximately 20 minutes before the vehicle was stopped for a component diagnosis. The inner brake lining temperature reached 1,262°F and the brake fluid temperature inside the caliper reached 217°F. Field diagnosis of this event concluded that the leading piston, of the dual piston system, was seized in its bore, but only while the piston temperature was elevated. At room temperature, the next morning, the caliper operated normally.

APPENDIX

<u>List of Items in the Appendix</u>

Table 1 – Equipment Used to Test the Monaco Holiday Rambler Ambassador

Electronic Data Collection Package		
[illegible]	[illegible]	[illegible]
Computer Case	MB1PC6N	Cyber Research Inc
Pentium Computer	90 MHz P1	Cyber Research Inc
LCD Display	10.4-in	Cyber Research Inc
[illegible]		
Temperature Modules	3B47	Analog Device Inc
Signal Conditioners	3B18	Analog Device Inc
16-Channel Backplane	3B01	Analog Device Inc
DC Power Supply	KW40-12-15T797	Polytron Devices Inc
[illegible]		
Hi-Temp Probe J-type thermocouple, inserted through T-fitting welded to OEM bleed valve into caliper (4)	20-HH40	Marlin Mfg Corp
J-Type Thermocouple (for inner brake pads) (4)	J-20-1-305	Watlow Gordon
Performance Monitor	625	Lab Equip Corp
Fifth Wheel (initial speed and stopping distance)	5101	Lab Equip Corp
Vehicle Decelerometer	141 4G	Setra Corp
Brake Pedal Force Display for driver	3100A	GSE Inc
Brake Pedal Force Transducer (300 lb)	114350-01301	GSE Inc
Brake Pedal Position Linear Potentiometer	M2078-8-10	Maurey Instrument Corp
Brake Fluid Pressure Transducer (2500 psi) (4)	PSI 100	PSI-Tronix Inc
Videotape Equipment Package		
Videotape System Hardware	**Model**	**Manufacturer**
Digital CCD Color Camera (2)	KCC 310ND PD	KoCom Co
Lenses - 2.8 to 12mm CS-mount (2)	1:1.4 Ratio Auto Iris	Tamron USA Inc
Digital CCD Color Camera (2)	WV-C_352	Panasonic
Lenses - 4.5mm Computar® CS-mount (2)	1:1.4 Ratio Auto Iris	CBC (America) Corp
Multivision Quadprocessor (4-to-1 view splitter)	MV85	Robot Corp
DV Cam Cassette Recorder	SDRV10	Sony Corp
DV Cam Cassette Recorder	GVD900	Sony Corp
DV CamCorder (used as cassette recorder)	DSR PD100A	Sony Corp
DV CamCorder (used as cassette recorder)	DSR PD100A	Sony Corp
DV CamCorder (used as cassette recorder)	DSR PD100A	Sony Corp
DV Cam Shoulder Camera	DSR 300A	Sony Corp
13" Monitor (for fire suppression monitor)	CM8762074G	Magnavox/Phillips Elec
Power Supply (modified to limit to 12-vdc)	RS-35M	Astron Corp
[illegible]		
Handheld Extinguisher, 20 lb halon, modified by VRTC with manual T-handle shutoff valves and ducted to solenoids for fire suppression package (2)	398 Halotron	Amerex
Solenoid Valves, to control halon bottles (8)	02F20C1103A1F	Parker Corp
Pressure Switches, to monitor duct charge (2)	10-C12	United Elec Controls Co
Cone Jet Nozzles, brass, two per caliper (8)	2101315	TSC Co
Fire Suppression Control Panel	1	VRTC
Handheld Extinguisher, 20 lb ABC dry chemical	A411	Amerex
Handheld Extinguisher, 5 lb, CO2 (2)	322	Amerex
Handheld Extinguisher, 5 lb, Halotron	3806T	Amerex

Figure 1 - 2001 Monaco Holiday Rambler Ambassador

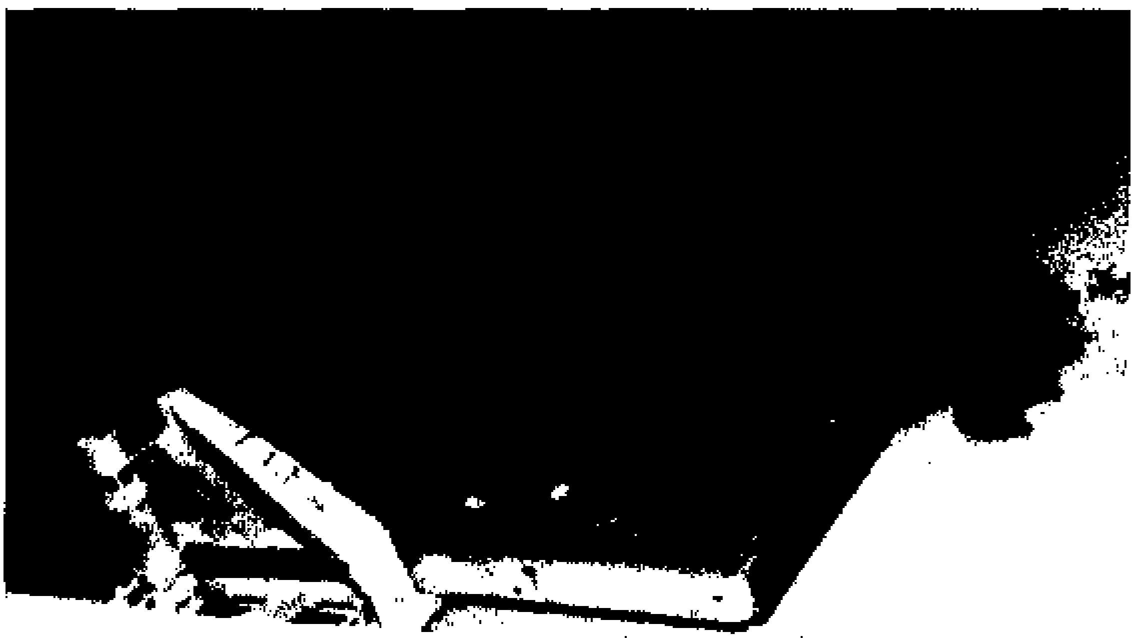

Figure 2 – Front Axle (AXL1) As Received at the VRTC

Figure 3 – Instrumentation Package Showing Data Collection Computer, Signal Conditioners, LCD Monitor, and the Video Monitor for the Fire Suppression System

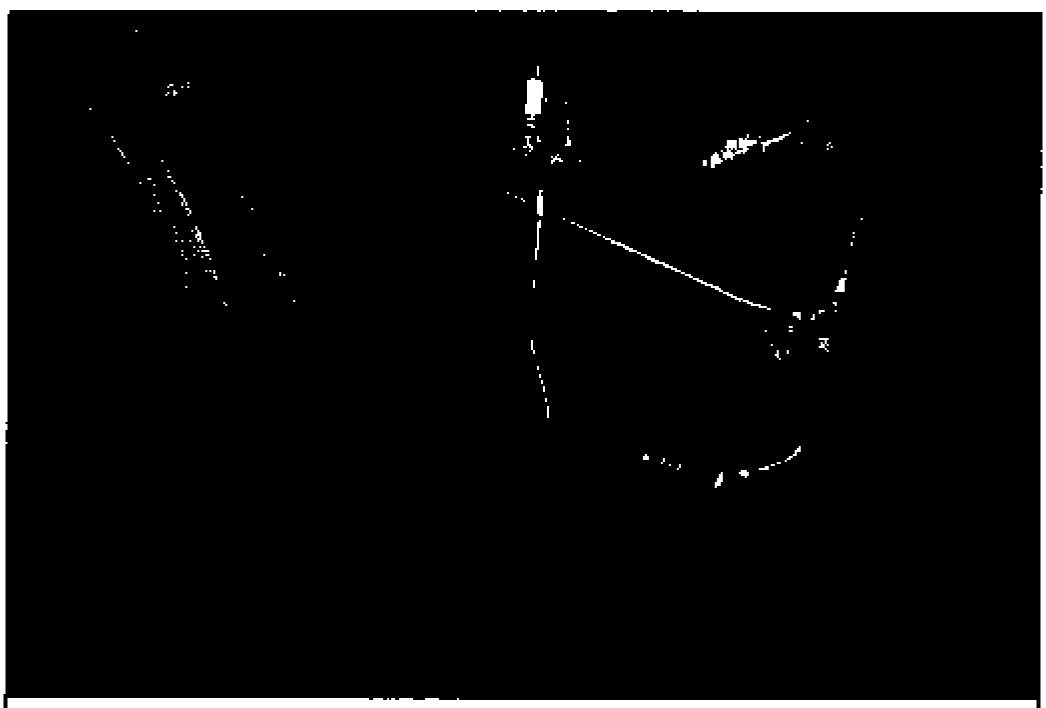

Figure 4 – Wheel-end Instrumentation Showing the Fire Suppression Nozzles and the Thermocouple Probe Inserted into the Caliper through a Modified Bleeder Valve

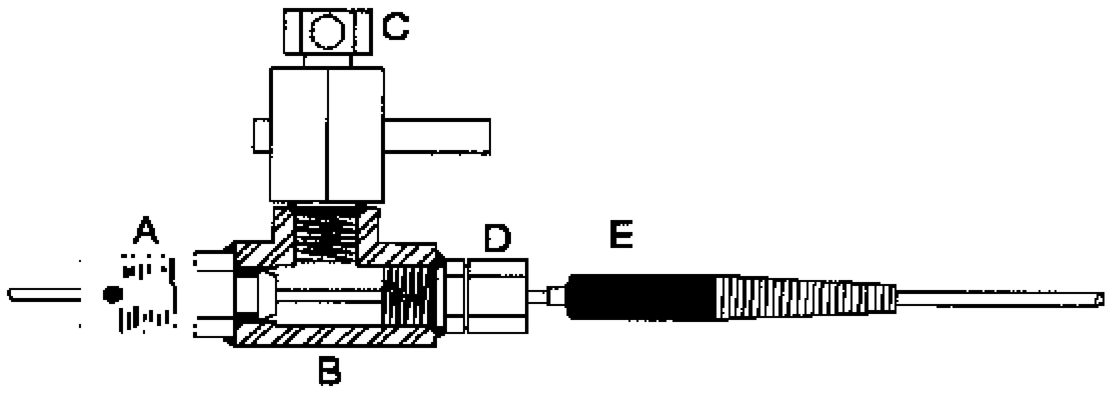

Figure 5 – Installation of the Thermocouple to Measure Brake Fluid Temperatures Inside the Caliper; Probe Inserted through the Bleeder Valve

Component Notes: (A) OEM Bleeder Valve Modified by Sealing the Hole on the Sidewall Below the Threads and Drilling a New Hole Through the Bottom (Left Side in the Picture) of the Valve for Passage of the Probe, (B) T-Fitting Silver Soldered onto the Bleeder Valve, (C) New Bleed Port, (D) Compression Fitting, (E) Thermocouple Probe

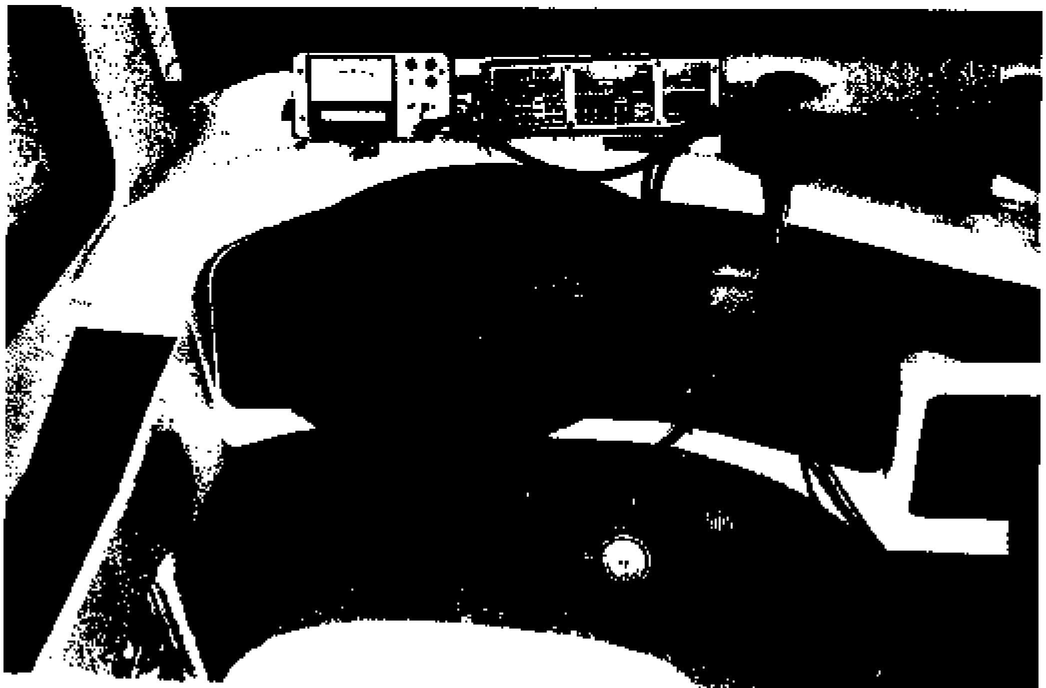

Figure 6 – Instrumentation for the Brake Pedal Force and Travel and the Driver Display for Vehicle Speed/Distance and Brake Pedal Force

Figure 7 – Videotape Recorders (Used Three DV CamCorders as Recorders) and the Quadprocessor for the 4 (Wheel-ends)-into-1 Composite View

Figure 8 – Videotape Camera Position and Fire Suppression Nozzle Position for the Right Front Wheel

Figure 9 – Fire Suppression Package Consisting of the Halon Cylinders, Solenoids, and Pressure Valves Located in the Vehicle Storage Bay

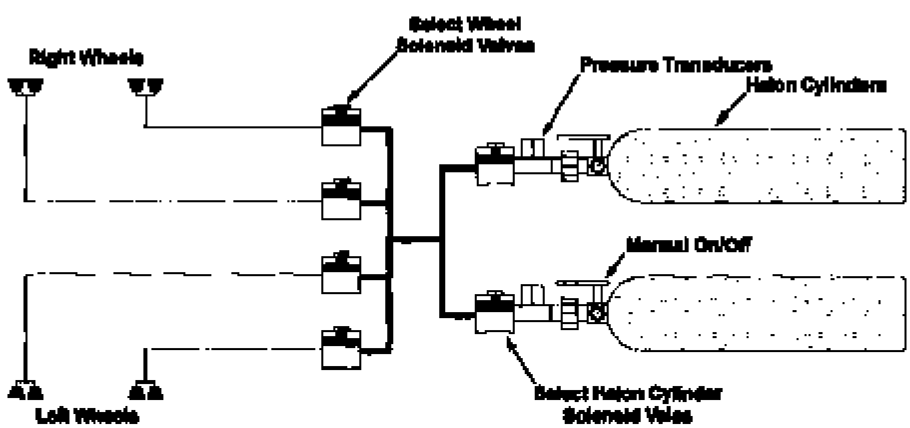

Figure 10 – Schematic of the Fire Suppression System

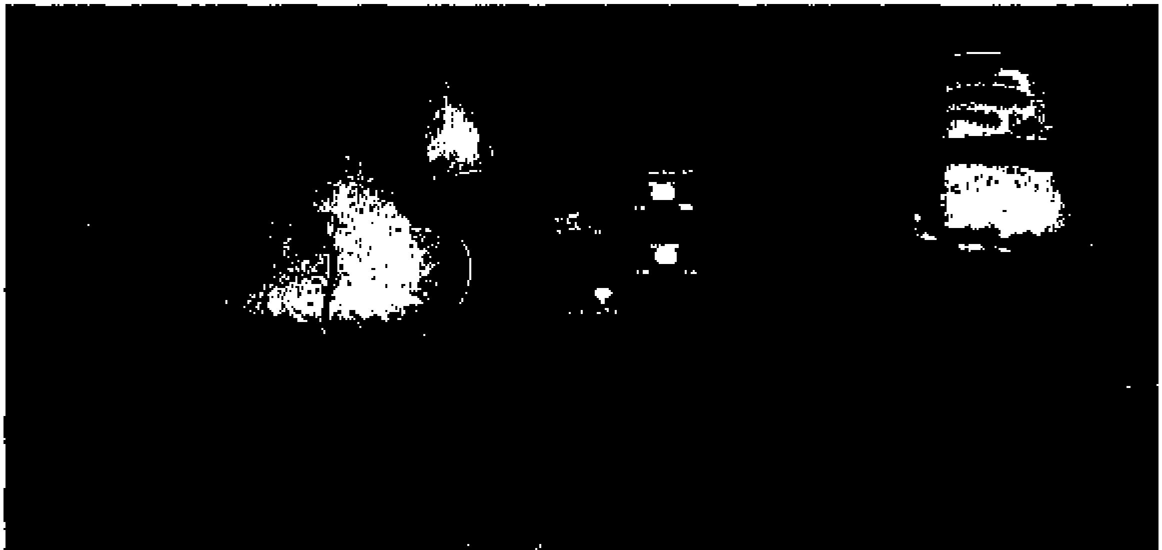

Figure 11 – Control Panel with Master On/Off Toggle, Green Push Activation Buttons (One for Each Wheel), Yellow Lights to Indicate if the Primary and Secondary Halon Cylinders have Pressurized the Fire Suppression System, and Red Push Buttons to Activate Each Halon Cylinder

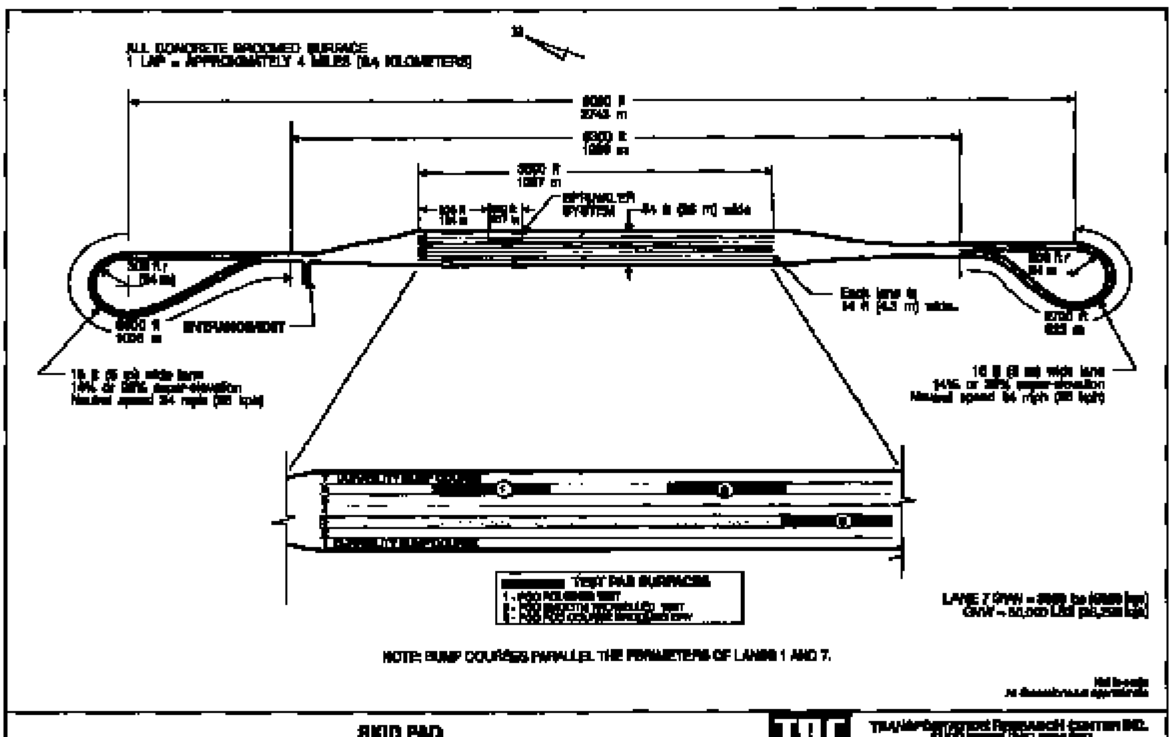

Figure 12 – The TRC Skid Pad with the Straightaway Test Area and the North and South Turning Loops

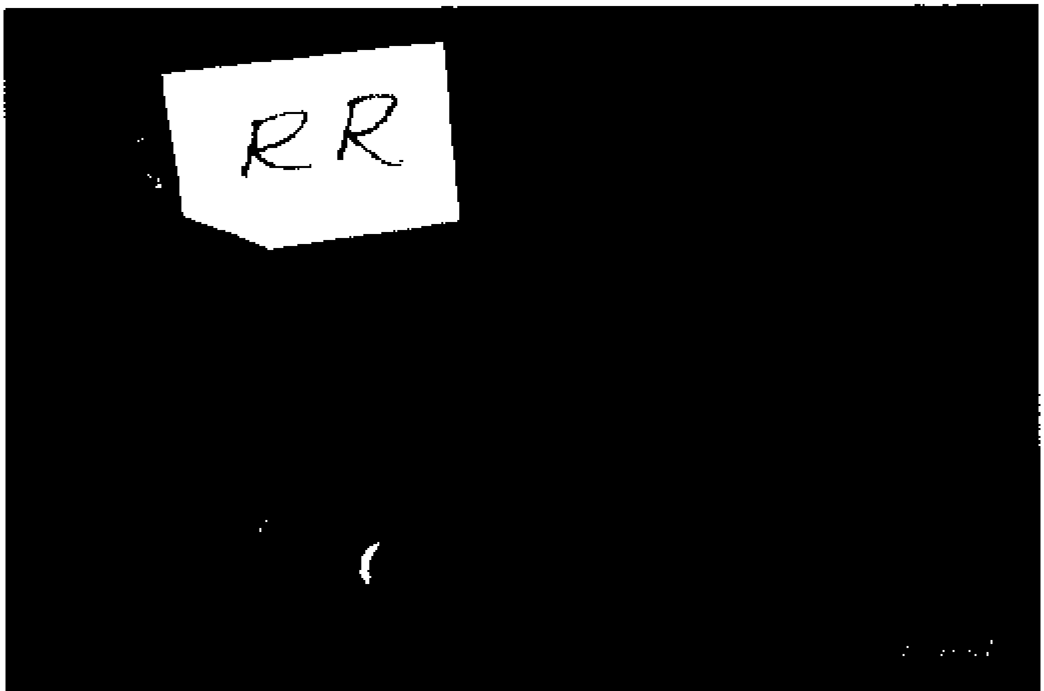

Figure 13 – View of As Received Right Rear Wheel Showing the Melted ABS Sensor on the Wheel-end Reported to have had a Fire

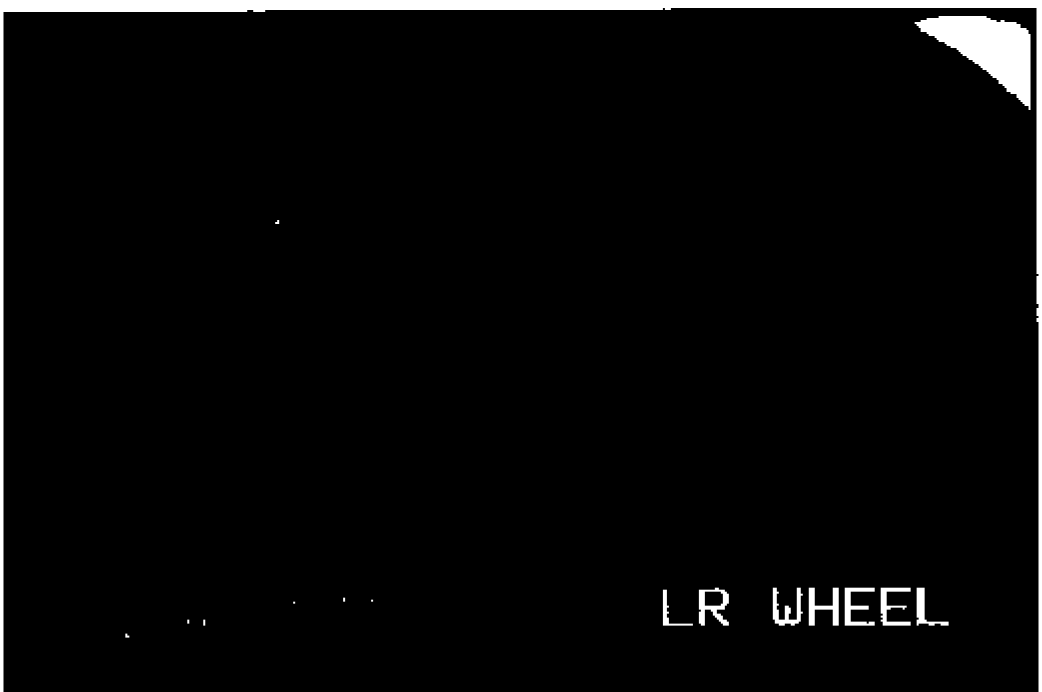

Figure 14 - Left Rear Brake Rotor was Glowing Red at 50 Minutes into the First Test on MH1 (Most of the View of the Rotor is Blocked)

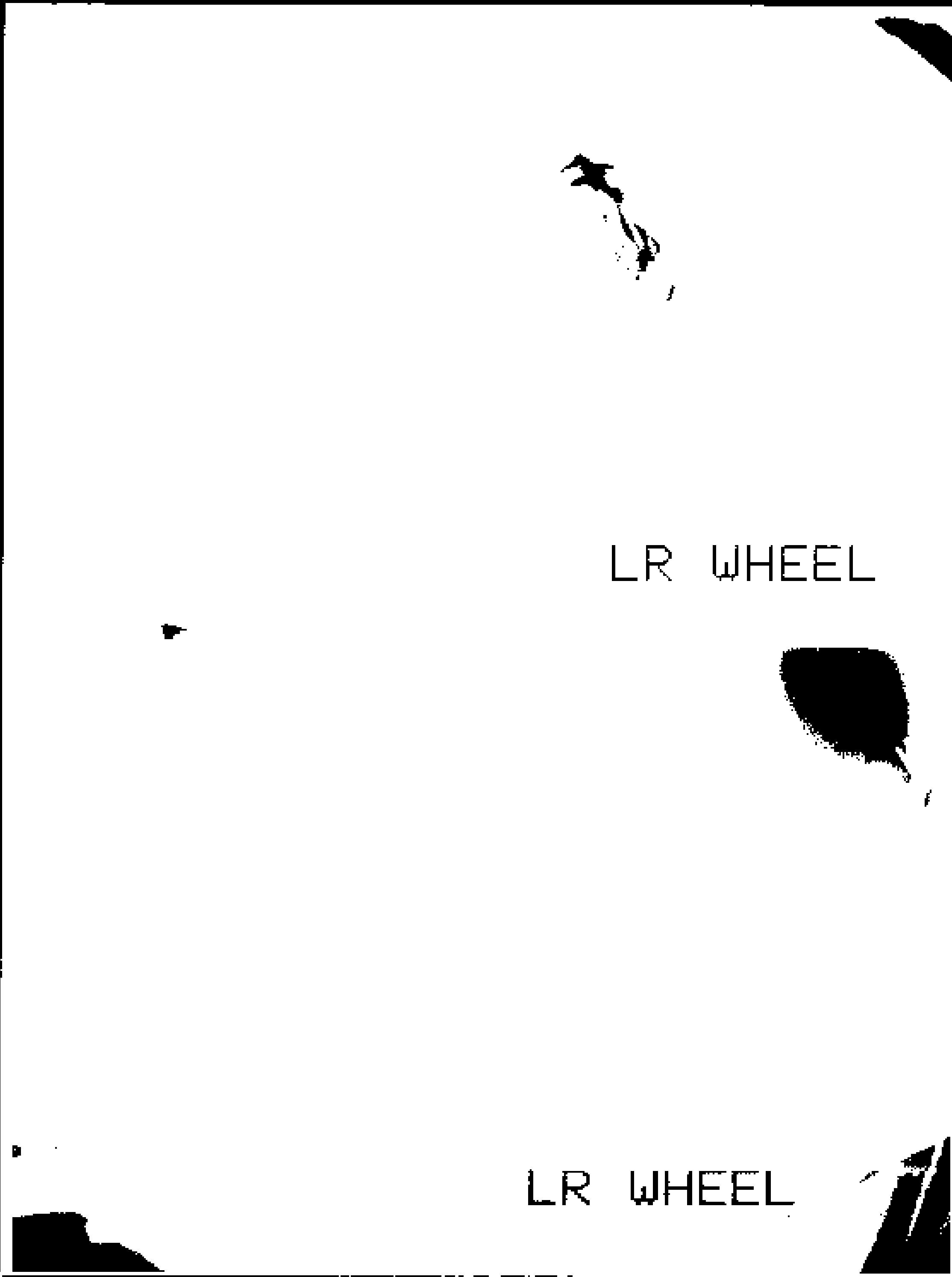

Figure 15 – Left Rear Wheel Fire at 55 Minutes into the First Test on MH1

Note: In the upper view, the auto-iris circuitry of the videotape camera malfunctioned during this test. The lower view, from the replacement camera, shows the same field of view for comparison.

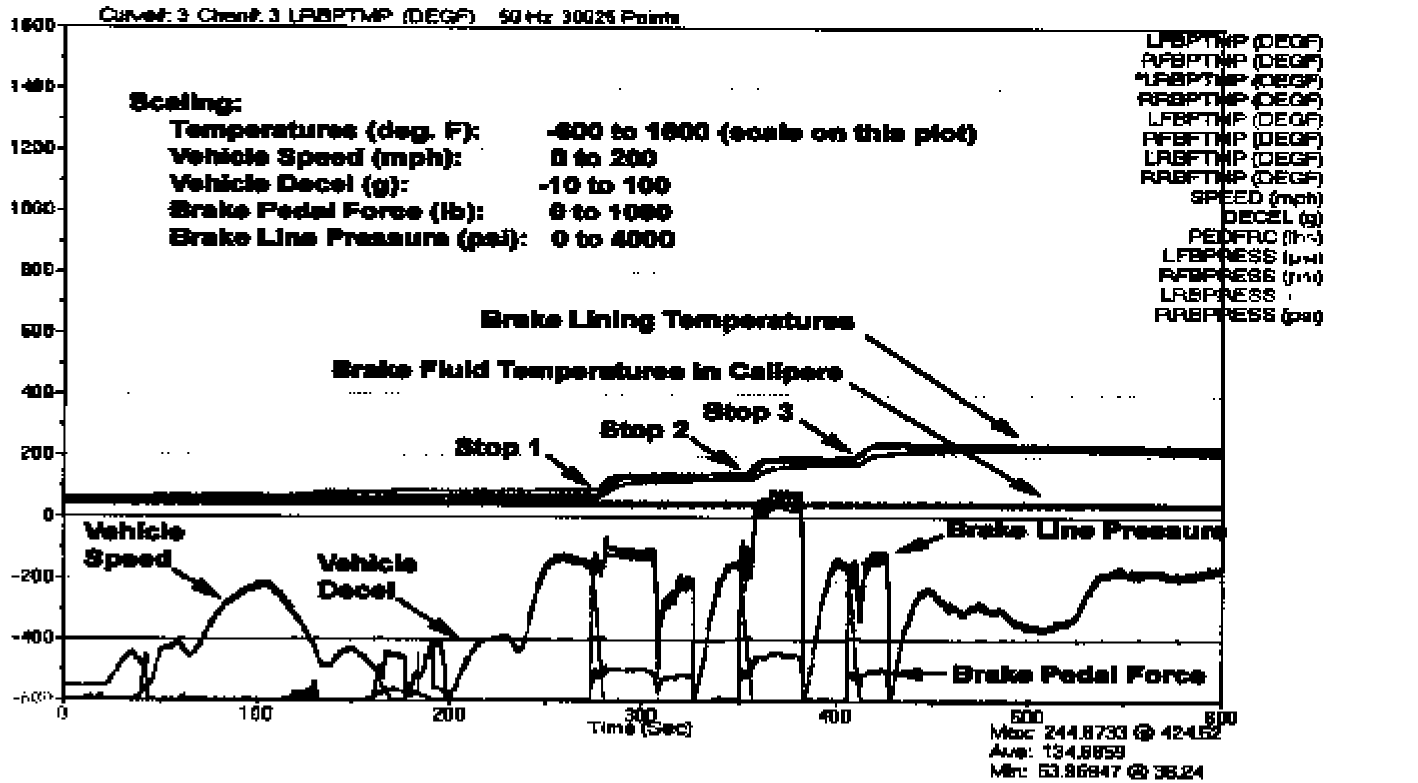

Figure 16 – Data for First Test on MH1 Showing the Drive Out to the Skid Pad and the First 200°F Target Stops

(Notice the rise of the inner brake lining temperatures compared to the four caliper fluid temperatures)

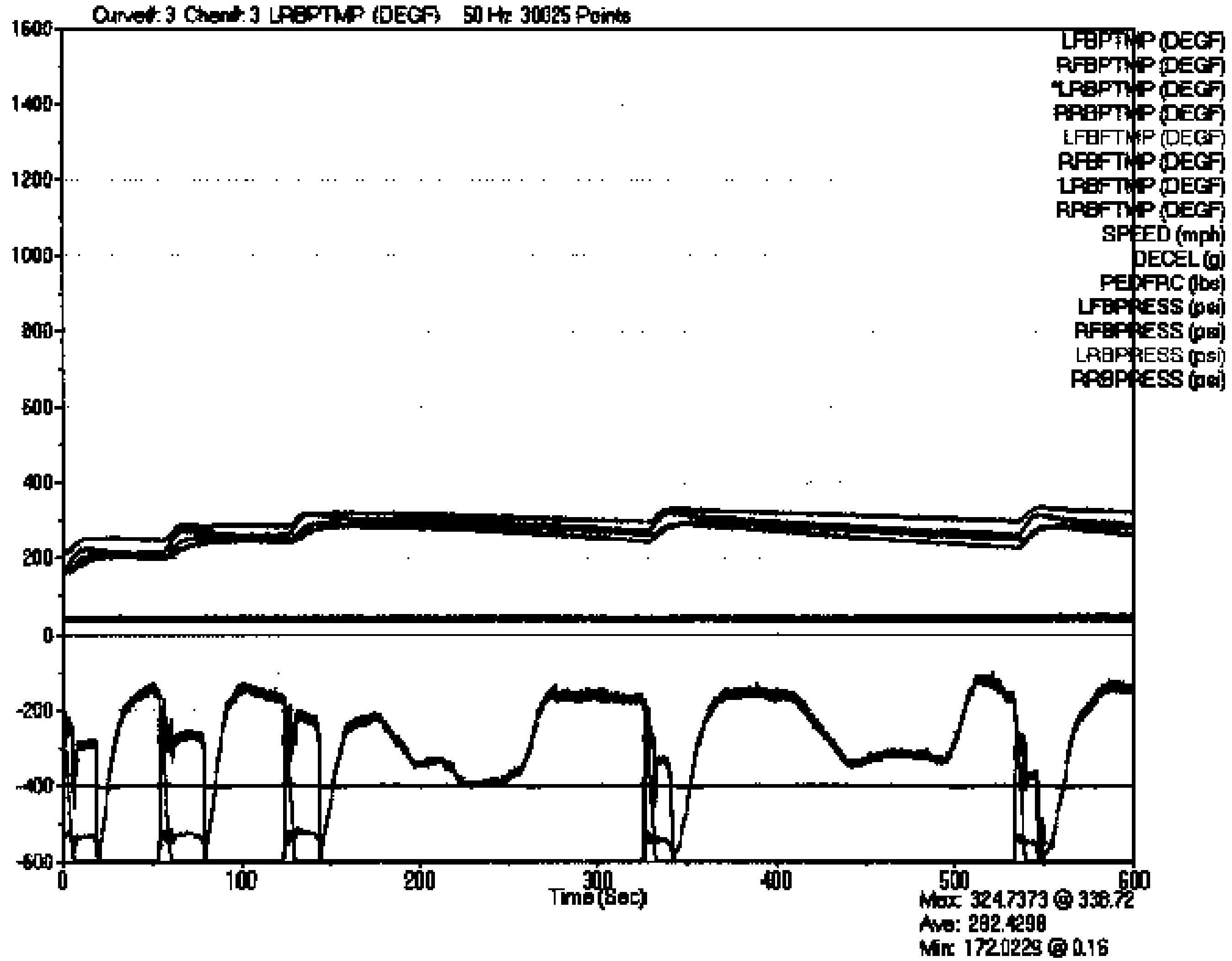

Figure 17 – Data for First Test on MH1 Showing the 300°F Target Stops
(Notice the left rear inner brake lining temperatures are running lower than the right rear and the brake fluid temperatures are 40 to 50°F)

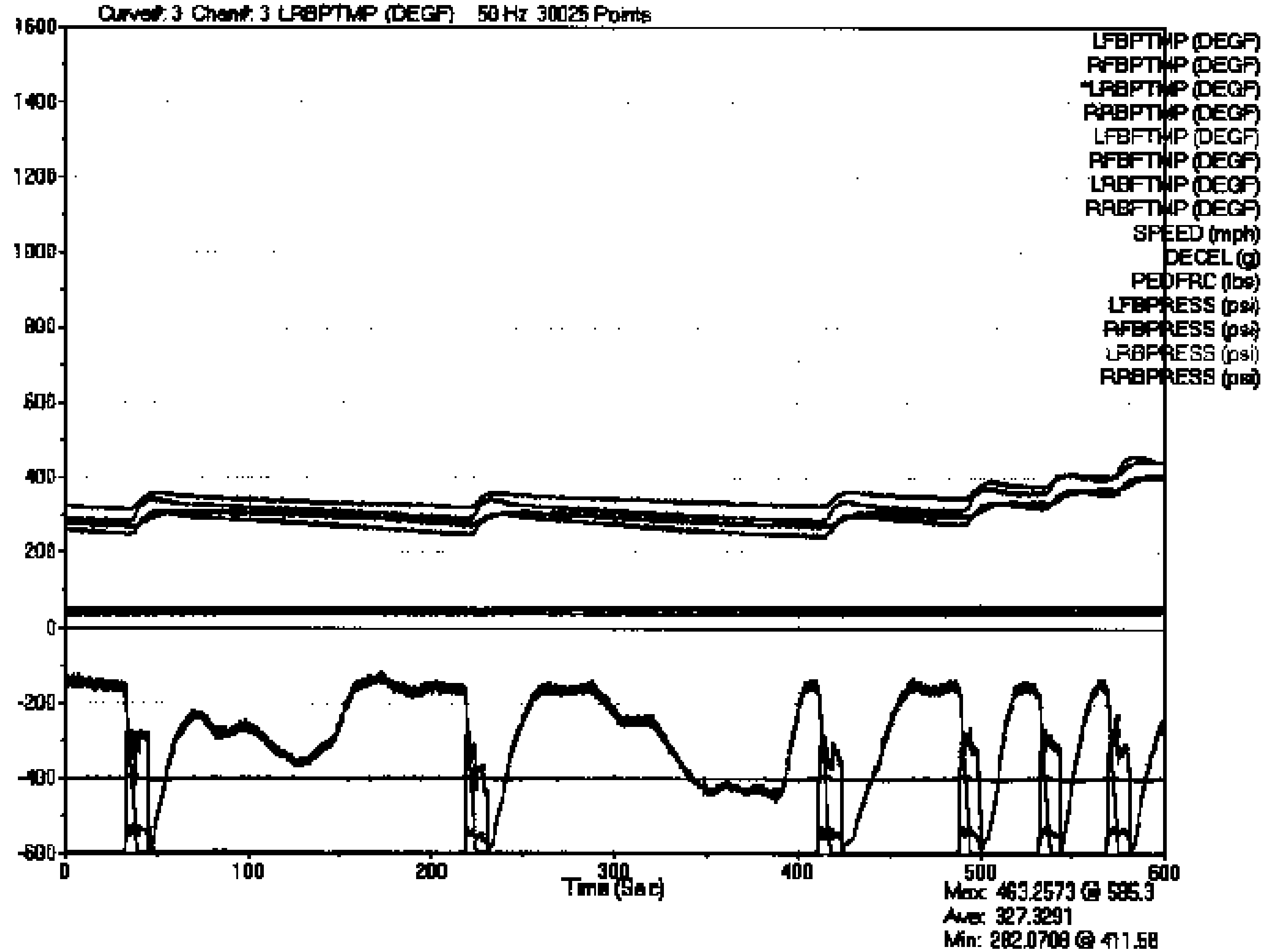

Figure 18 – Data for First Test on MH1 Showing the 400°F Target Stops
(Notice minimal heat buildup in the brake fluid inside the caliper)

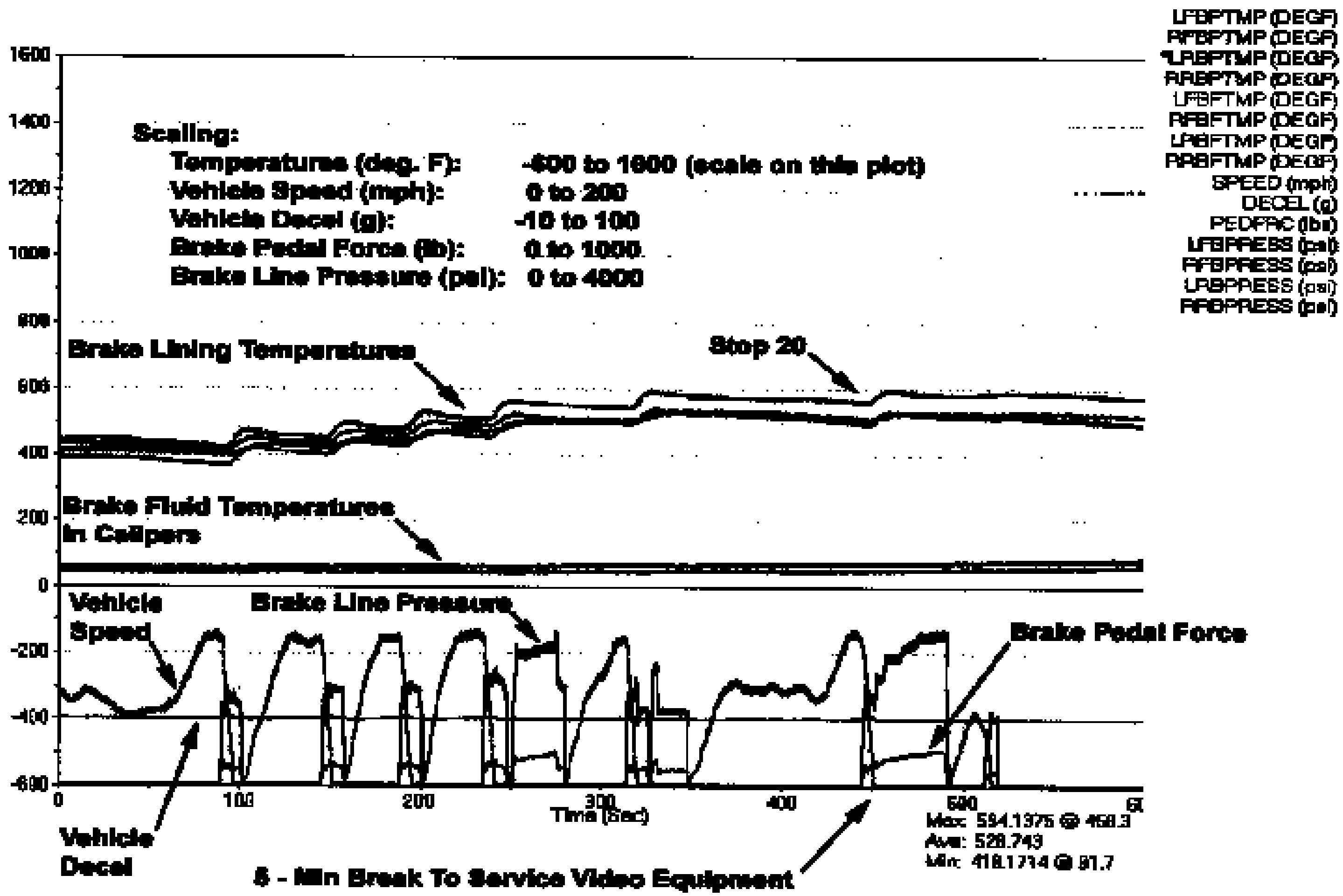

Figure 19 – Data for First Test on MH1 Showing the 500°F Target Stops

(Notice the left rear inner brake lining now has the highest temperature

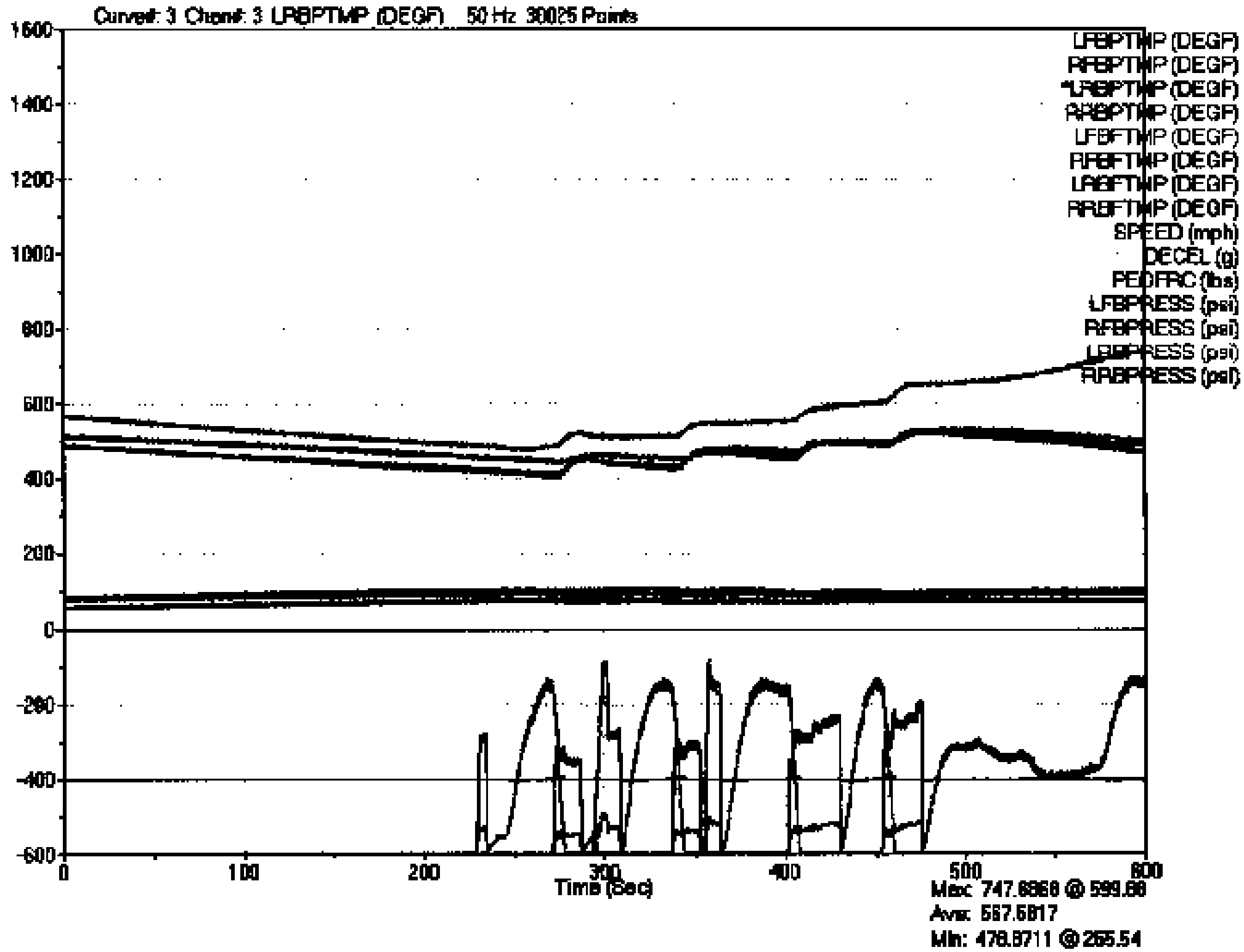

Figure 20 – Data for First Test on MH1 Showing the End of the 5-Minute Break (for the Video Equipment), the Next Four Brake Applications, and the Beginning of the Abnormal Rise in the Left Rear Brake Lining Temperature

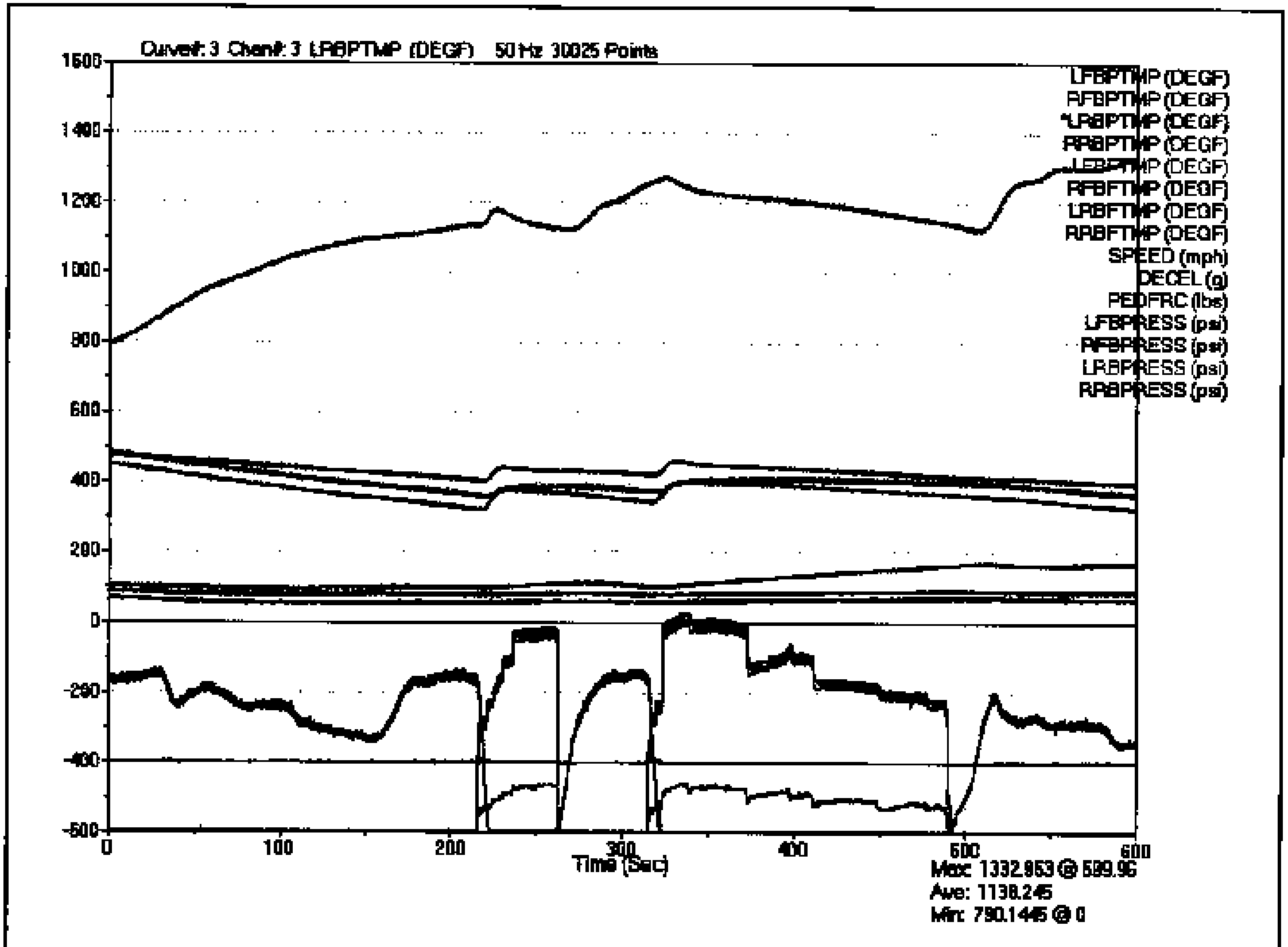

Figure 21 – Data for First Test on MH1 Showing the Abnormal Thermal Rise Continuing

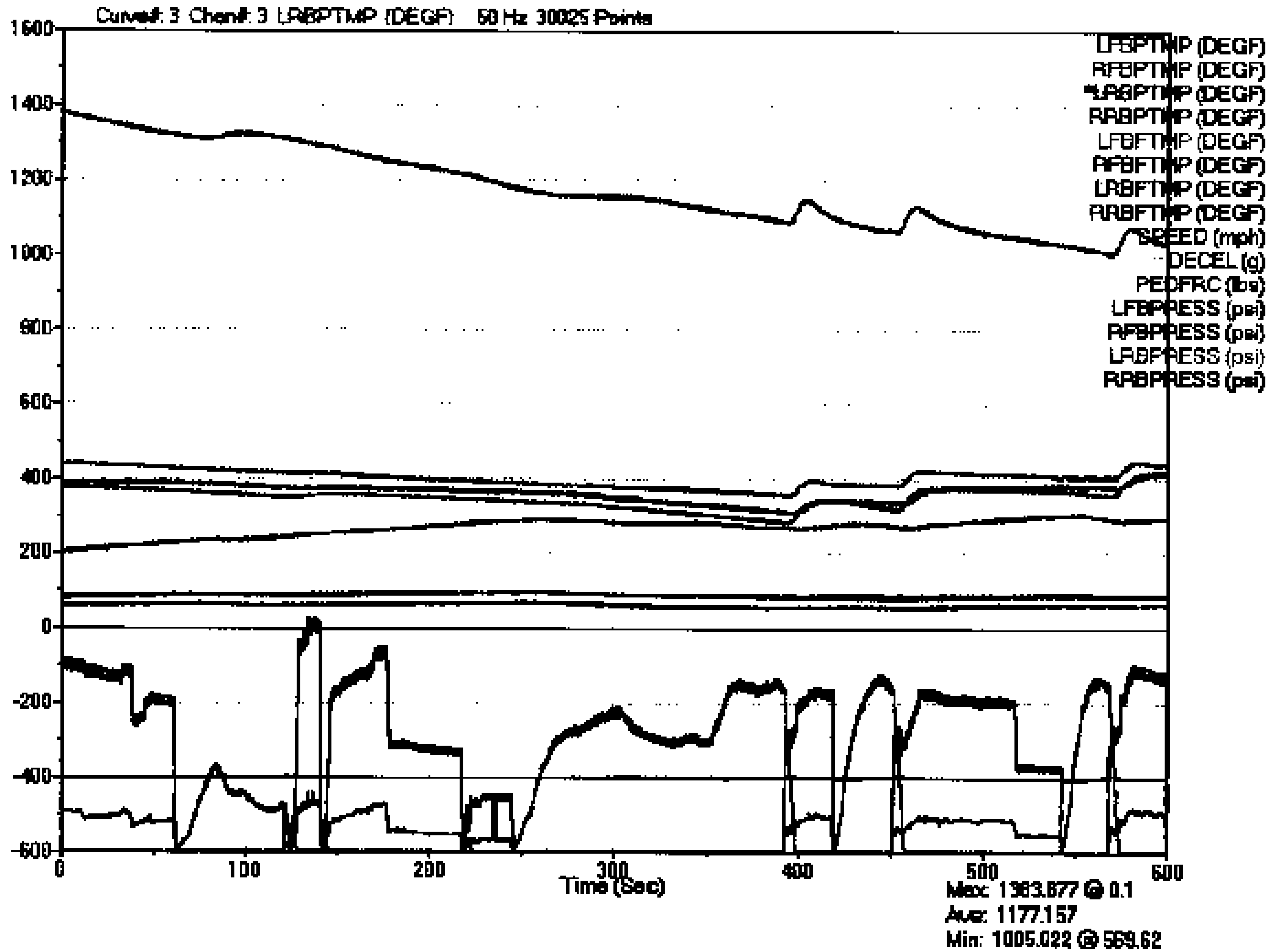

Figure 22 –Data for First Test on MH1 Showing a Decline in the Abnormal Temperature on the Left Rear Lining
(Notice more braking does not restart the abnormal thermal event)

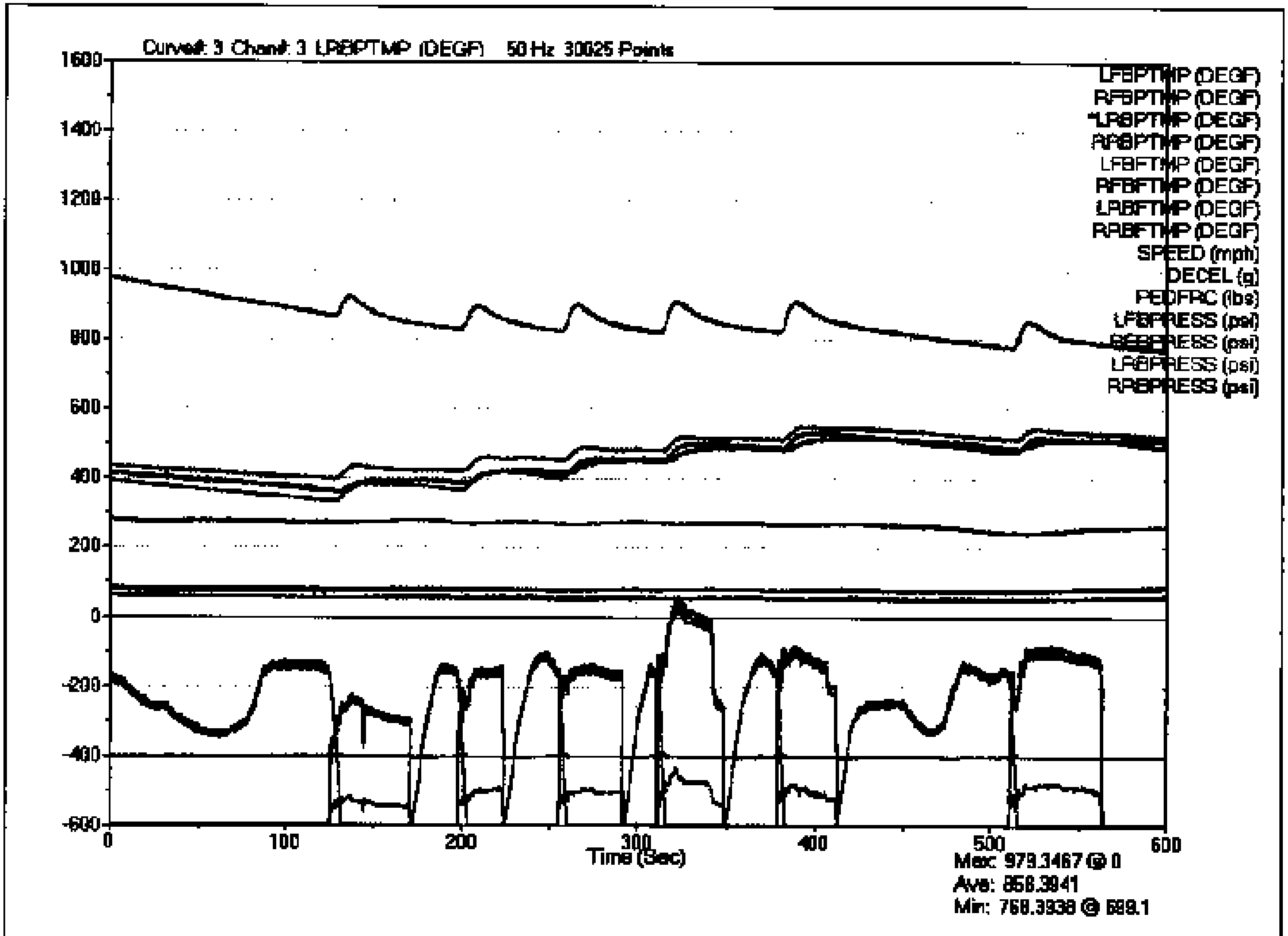

Figure 23 –Data for First Test on MH1 Showing the Temperature of the Left Rear Lining Declining as Additional Braking Does Not Restart the Event
(Notice the left rear brake fluid temperature rising to 306°F)

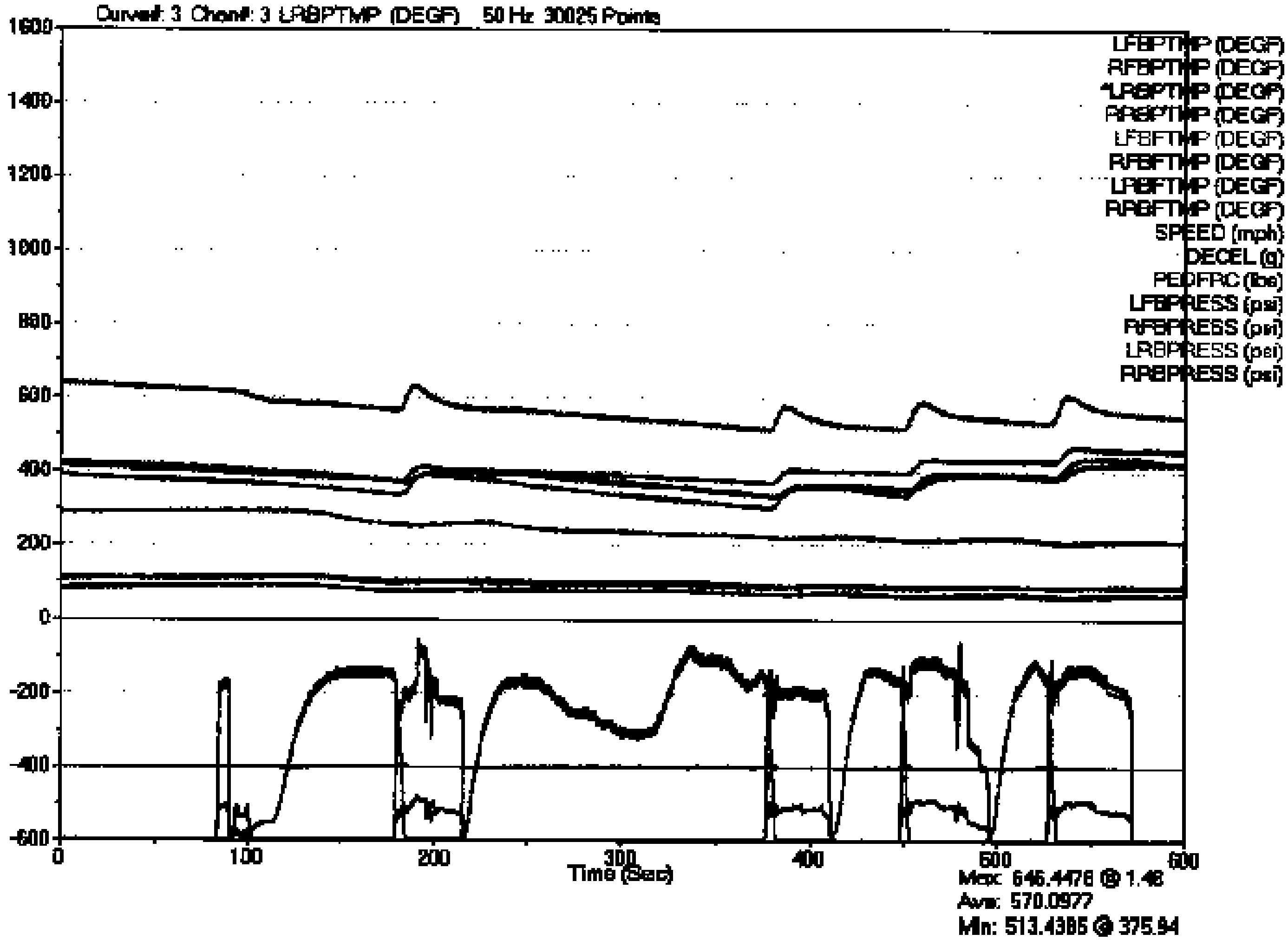

Figure 24 – Data for First Test on MH1 Showing the End of the Abnormal Thermal Event before a Field Inspection of the Components Could be Conducted

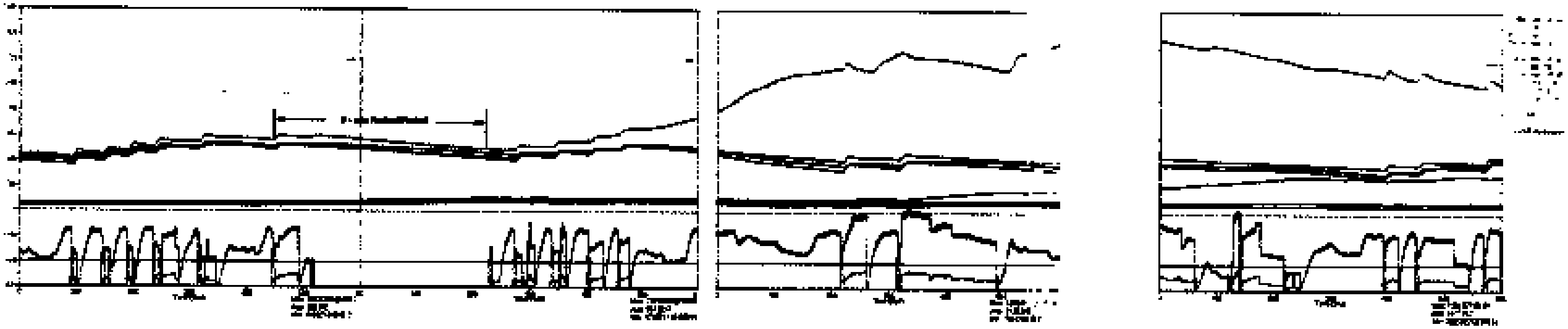

Figure 25 – Composite Data for the First Test on MH1 Showing Normal Brake Stops, a 5-Minute Break or Parked Period (to Service Video Equipment), and the Thermal Deviation of the Left Rear Inner Brake Pad after Four More Brake Stops (Temperatures Reached 1,400+°F)

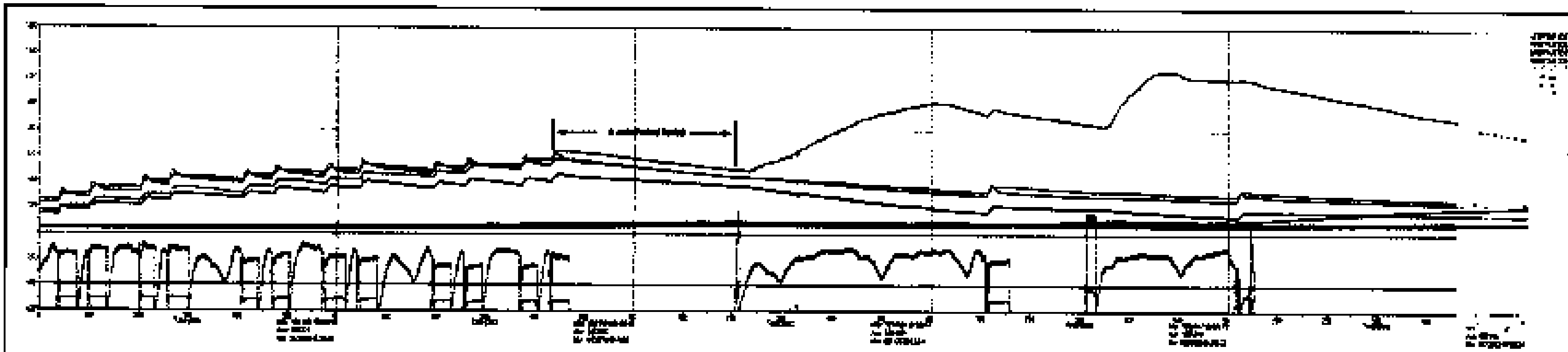

Figure 26 – Composite Data for the Second Test on MH1 Equipped with AXL1 Showing Normal Brake Stops, a 4-Minute Parked Period, and Thermal Deviation of Right Front Inner Brake Lining While Driving without Braking (Temperature Reached 1,262°F)

Figure 27 – The Second Test on MH1 Showing the Right Front Rotor was Red Hot and Shooting Sparks (at Bottom of Rotor) from a Dragging Brake

Table 2 – Tests Conducted on MH1

41	0	Skid Pad	LR Fire	
15	0	VDA	RF Red Rotor	installed AXL1
42	0	HSTT	no event	
77	21	Skid Pad	no event	
18	32	Skid Pad	no event	
23	26	HSTT+VDA	no event	ABS repaired
19	18	Skid Pad	no event	

Table 3 – Inspection Data from Post-Test Removal of Calipers

[illegible]		[illegible] – Left Front [illegible]	[illegible] – Right Front [illegible]	[illegible] – Left Rear [illegible]	[illegible] – Right Rear [illegible]
Rotor Appearance:		good used rotor - no grooves, no [illegible] rust, or rust	slight grooves with rust and deposited material	slight grooves with rust and deposited material	slight grooves with rust and deposited material
Hub Turning Torque:		[illegible] eakaway [illegible] sly running	5 ft-lb static breakaway *A 6 ft-lb continuously running	[illegible] static breakaway [illegible] continuously running	52 ft-lb [illegible] away 41 ft-lb [illegible] ly running
Brake Linings: (attempt to rattle brake linings with Vise-Grips on backing plates)		[illegible] pads free [illegible] ing on brake pads	inner and outer pads free caliper not binding on brake pads	inner and outer pads free [illegible] not binding on brake pads	inner [illegible] ads free caliper [illegible] on brake pads
Attempt to move caliper:	Radially:	[illegible] ment	0.008"	little to no movement	little to [illegible] ent
	Tangentially:	little to no movement	0.013"	little to no movement	little to no movement
Inspect Pin Boots:		both boots intact	both boots intact	upper boot ripped and lower boot intact	both boots intact
Inspect Pin Bolts:		good condition	good condition	good condition	good condition
Inspect Pin Flange Position:		upon initial inspection neither was cammed, now both are cammed and leading pin flange "driven" into caliper casting, initial paint index marks moved	initial and final inspection found neither pin flange was cammed, no change on paint index marks	initial and final inspection found top pin flange barely cammed and bottom not cammed, no change on paint index marks	neither pin flange cammed, no change seen from initial inspection paint index marks
Pin Bolt Breakaway Torque:	Leading:	52 ft-lb (torque wrench)	not measured - but tight	60 ft-lb (torque wrench)	60 ft-lb (torque wrench)
	Trailing:	52 ft-lb (torque wrench)	not measured - but tight	60 ft-lb (Chatillon pull on 1-ft wrench)	60 ft-lb (Chatillon pull on 1-ft wrench)
Inspect Pin Bolts:	Leading:	green "patch" material	not performed	not noted	not noted
	Trailing:	not performed	not performed	removed lower bolt, remove brake pads, reinstall lower bolt - caliper binds as torque is applied	removed bolt and found white & blue "lock" material
Check Caliper Slide Force: (then set caliper aside)	Inboard:	12 lb	25 lb	100 lb (13 lb after rotating pin 180°) *B	not performed
	Outboard:	10 lb	20 lb	35 lb (12 lb after rotating pin 180°)	not performed
Twist and Insert Pins in Anchor Plate:		free sliding	free sliding	free sliding	free sliding
Hub Turning Torque (w/o linings/calipers):		10/5 ft-lb breakaway/running	not performed	31/26 ft-lb breakaway/running	31/25 ft-lb breakaway/running
Measure Pin Free Play (in Anchor Plate Bore) *C Pin was Pushed to Compress Boot, then Released, Pin Moved to Neutral Position, then Free Play was Measured	Leading: x =	0.014"	not performed	0.005"	0.005"
	y =	0.030"	not performed	0.009"	0.009"
	r =	0.013"	not performed	0.008"	0.008"
	t =	0.018"	not performed	0.009"	0.009"
	Trailing: x =	0.038"	not performed	0.024"	0.021"
	y =	0.036"	not performed	0.024"	0.025"
	r =	0.057"	not performed	0.018"	0.025"
	t =	0.026"	not performed	0.020"	0.024"
Insert 2-1/2 Inch Wooden Block and Hand Apply Brake Pedal to Extend the Pistons:		not performed (axle was removed from vehicle at time of inspection)	five brake applications to drive the pistons to the wooden block, fairly even deployment, upon release the wooden block was easily removed *D	five brake applications to drive the pistons to the wooden block, both pistons even after first two applies, lead piston behind trailing piston, then both even at block, upon release the wooden block was easily removed	five brake applications to drive the pistons to the wooden block, lead piston was 1/2 in behind trail piston, then both even at block, upon release the wooden block was easily removed
Metal Bar and C-clamp Retract Piston:		not performed (axle was removed from vehicle at time of inspection)	normal piston return into bore *E	normal piston return into bore	normal piston return into bore
Condition of Caliper		used, but apparently good condition	piston environment boot very thin and ripped toward center of caliper	piston environment boots burnt, 100% of each boot	piston environment boots burnt, 25% of each boot in middle of caliper
Condition of Brake Linings		appears used, some glazing, evidence that pads had been installed in both orientations, were backwards as found	appears used, some glazing, sort of "dried" out, some white smoke stain along edges	appears used, some glazing, sort of "dried" out, white smoke stain along edges, corners of pad breaking off	appears used, some glazing, sort of "dried" out, some white smoke stain along edges

Notes:
*A = 140 ft-lb rotational torque was measured on the test track ten minutes after the stopping with a red-hot rotor; during teardown the next day, the torque had dropped to 5 ft-lb
*B = 50-lb slide force maximum allowed by Bosch updates
*C = Pin Free Play Measurement => x = horizontal, y = vertical, r = radially, t = tangentially
*D = the lead piston was immobile when brake pedal was actuated by hand immediately after the event
*E = piston could not be pushed back into the bore on the test track immediately after the event

Figure 28 – Post-Test Inspection of the Left Front Wheel-end of AXL1 Showed the Rotor Brake Surface Became Polished

Figure 29 – Post-Test Inspection of the Left Front Wheel-end of AXL1 Showed the Outer Brake Pad Had Evidence of Being Previously Installed as the Inner Brake Pad of the Caliper

Figure 30 – Post-Test Inspection of the Right Front Wheel-end Showing the Overall Appearance of the Rotor

Figure 31 – Post-Test Inspection of the Right Front Wheel-end Showing the Slight Grooving and the Apparent Transfer of Material to the Rotor

Figure 32 – Post-Test Inspection of the Right Front Wheel-end Caliper Showed the Leading Piston Now Has a Torn Boot

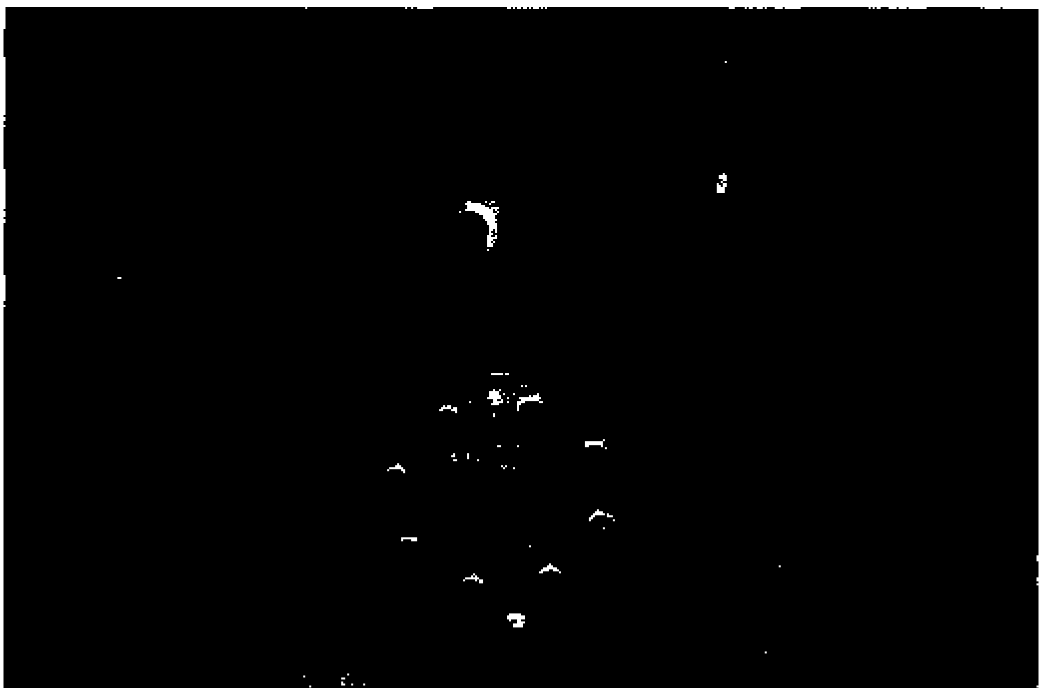

Figure 33 – Post-Test Inspection of the Right Rear Wheel-end Showed Slight Grooving and Apparent Transfer of Material onto the Rotor

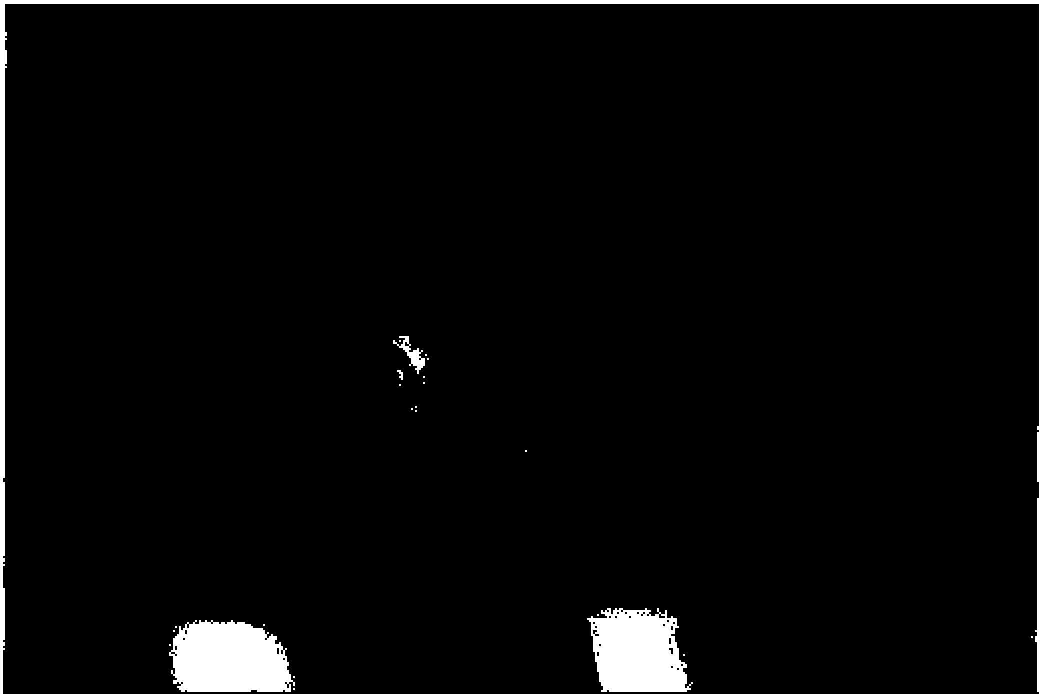

Figure 34 – Post-Test Inspection of the Right Rear Wheel-end Showed Evidence of a Fire Event Reported by the Previous Owner

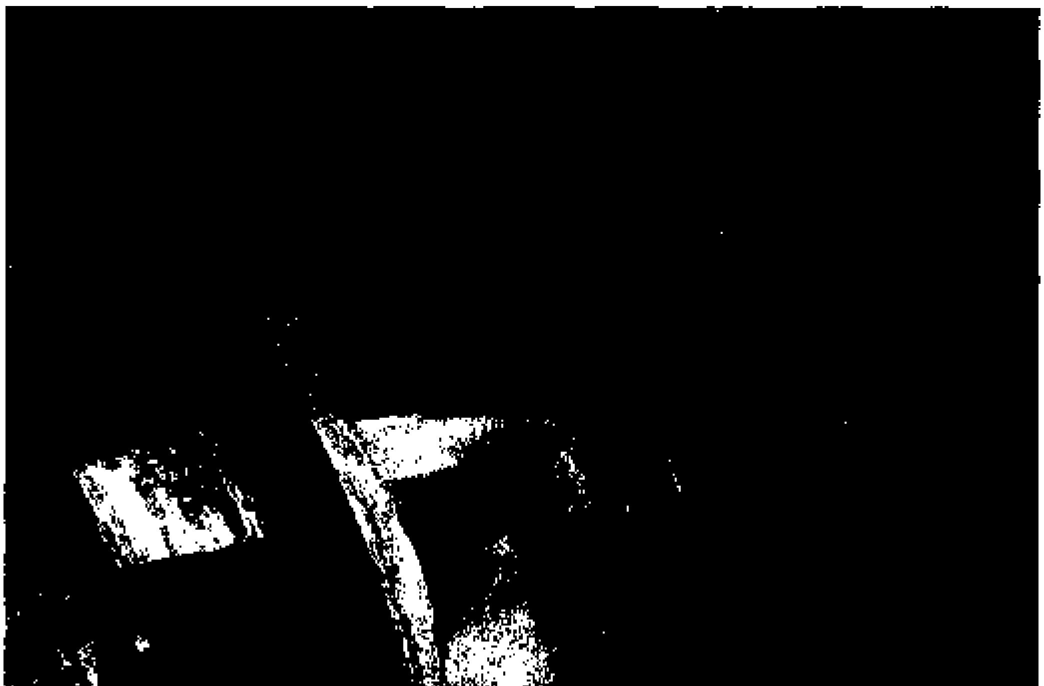

Figure 35 – Post-Test Inspection of the Left Rear Wheel-end Showed Slight Grooves and Apparent Material Transfer
(Note that this wheel was on fire during the tests at VRTC)

Figure 36 – Post-Test Inspection of the Left Rear Wheel-end Showing the Determination of the Caliper Slide Force

Figure 37 –Post-Test Inspection of the Left Rear Wheel-end Showed the Condition of the Caliper after the Fire during the First Test