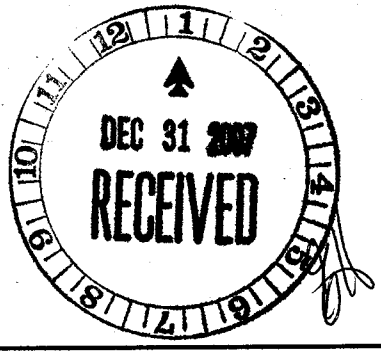
U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**



Memorandum

Vehicle Research and Test Center **P.O. Box B37
East Liberty, Ohio 43319
(937) 666-4511**

Subject: FINAL REPORT: "Workhorse-Bosch Trip Report"

Date: DEC 2 8 2007

From: Michael W. Monk
Director, Vehicle Research and Test Center

Reply to Attn. Of: NVS-310

To: Kathleen DeMeter
Director, Office of Defects Investigation

NVS-210

Attached are four (4) copies of the subject report. This completes the requirements for this program.

Attachment:
Final Report

#

Workhorse-Bosch Trip Report

Date: November 13&14, 2007

Destination: Monument Chevrolet
3940 Pasadena Freeway
Pasadena, TX 77503

Participants: Charles Shomper, owner
Hennie van Niekerk, Director of Engineering Services (Workhorse Custom Chassis)
Peter Cohen, title unknown (Bosch)
Peter Kivett, Investigator (Office of Defects Investigations)
Dan Pearse, Vehicle Safety Engineer (Vehicle Research and Test Center-DA Group)
Danny Barnett, Assistant Service Manager (Monument Chevrolet)
Clint, Service Writer (Monument Chevrolet)
Ray, Technician (Monument Chevrolet)
Andy, Technician (Monument Chevrolet)

Purpose: Examine a complaint vehicle that had experienced a thermal event at a wheel-end with representatives of the chassis and brake manufacturers.

Background: The complaint vehicle was a 2003 Fleetwood Flair, with Vehicle Identification No. 5B4MP67G533374597 and 8,500 miles. The Workhorse Vehicle and Service Information, supplied by the Workhorse representative, listed the Model No. as P32111, the wheelbase at 228 in, the GVWR at 22,000 lb, the GVWRF at 8,000 lb, and the GVWRR at 14,500 lb. The vehicle was reported (production data in the Information Request letter) to have been equipped with 66-mm diameter piston calipers on the front and rear axles. The ABS EHCU is made by TRW (Kelsey-Hayes EBC325 unit). A summary of the warranty repairs performed on this vehicle is shown below.

07/17/2003	1 mi	purchase inspection
07/22/2003	210	towing charge, check engine light on, tachometer connector partially connected
08/11/2003	444	reduced power, 10 mph max, TPS connector loose, installed new pins in connector
10/01/2004	1,922	towing charge, engine no start, battery bad cell, instrument cluster intermittently unreadable, instrument cluster exchange program
10/29/2004	1,986	engine power light on, replace throttle body and MAF sensor
06/03/2005	2,320	recall 50402C, only verify 2003 model year
08/09/2005	2,495	roadside assistance, no start, jumpstarted
09/26/2005	2,894	towing charge, reduced engine power, check engine light on,
10/04/2005	2,900	found faulty TAC module, reduced power message on, replace TAC module
10/18/2005	3,113	reduced engine power light on, unit lost power, pulled on harness and SES light came on, blue and black wires rubbing on intake manifold, replace and reposition
12/20/2005	3,268	replace engine cover latch
08/26/2006	5,297	backup camera inoperative, replace monitor and camera
07/05/2007	8,022	battery goes dead after vehicle sits for several days, replace battery

Results: The owner, representatives from the chassis and brake manufacturers, ODI, and VRTC met at the dealership and discussed the previous history of the vehicle with the owner. He was congenial and answered all questions with concise reasonable answers. He had driven the motorhome on several long trips of over 1,000 miles and multiple shorter trips. He has had his vehicle towed to dealerships for service three times, but the brakes had not been previously serviced. The owner did tow a Honda CRV without auxiliary brakes, and the Workhorse representative said that the GCWR would be exceeded for the chassis and the transmission. He was not towing when he had his mountain trip or when the event occurred, so that issue probably did not apply to this

situation.

Three months ago, the owner drove on a freeway from his covered storage parking area to a gas station to fuel the vehicle. After pulling into the gas station, he noticed a hot brake smell and found the "hub cap" of the right rear wheel was too hot to touch. After refueling, he drove back to the storage facility. As he was maneuvering to park in the tight covered space, the brake pedal "dropped to the floor", but did not result in a collision. When asked if his ABS light was illuminated, he responded "no".

The engineers and the owner continued the questions and answers on the 30-minute drive to the storage facility. The vehicle was briefly inspected to check several obvious items and to insure it was safe to drive. The brake linkage bellcrank was found to operate normally. The brake fluid level (DOT3) was normal and appeared to not be contaminated. The expected brake assembly silicone "goo" was present[1]. Bosch installs this silicone lubricant at several points in the brake system and it is normal for it to accumulate in the reservoir. The ABS sensors and the rotors were examined and found to appear normal, except that the right rear ABS sensor was melted and had fallen out of the metal sensor sleeve. The brake pedal was found to have normal travel, and would be expected to recover to the normal travel after cooling if the brake fluid had boiled at a wheel-end. If the brake fluid did boil at one wheel-end, the operator would still have the other hydraulic brake circuit to stop the vehicle.

The two manufacturer representatives and the ODI engineer rode with the owner as he drove approximately 20 miles from the storage facility back to the dealership along a freeway service roadway, as shown in Figure 1. This roadway was along a commercial strip with 45-mph speed limit and repeated stoplights. The owner appeared to be a competent, but not skilled, large vehicle driver (as to be expected). He was probably more aggressive accelerating and braking than a CDL driver. He also had the right-side wheels within inches of the curb for several hundred feet prior to the turn into the dealership, and then ran the right rear wheels over the curb turning into the dealership. He may have been self-conscience due to the riders with him. The ABS light was on during this drive.

Once at the dealership, the owner departed and the vehicle was driven into the truck bay relatively quickly. The vehicle was raised onto jack stands and the service technician immediately spotted the melted right rear ABS wheel speed sensor. The wheels were turned by hand with the transmission in neutral and the parking brake off. The front wheels were harder to turn than expected, but could be turned by one hand with a medium force. The rear wheels were expected to have more resistance than the front due to the drivetrain, but they were difficult to rotate requiring both hands and leaning body weight into the attempt. The bellcrank was checked and found to be free and returning to the full off position. The bleeder valves were opened one at a time resulting in a dribble at three calipers and a significant forceful squirt at the right rear caliper. This indicates trapped pressure to this one channel. The rear axle wheel-ends are supposed to have common brake line pressures, unless the ABS unit has closed the

1 International's *Diamondlife Disc Brakes UPDATE: Component Improvement* Participant Workbook TMT-3439 states on page 16, "Do not mistake silicone floating on the surface of brake fluid as contamination. If present, it will appear as a whitish substance floating in the master cylinder reservoir. The silicone grease is used in the original assembly process. This silicone material has the consistency of a light grease and can migrate to the master cylinder reservoir. Since the silicone is lighter than the brake fluid, it floats on the surface of the brake fluid and is often mistaken as "foreign matter" or contamination. The presence of the silicone is normal and does not affect operation of the master cylinder."

isolate valve and dumped one of the rear channels. The brakes were not "bled" after opening the bleeders since the manufacturer representatives reported that the height of the reservoir provided a larger pressure head than on a passenger car and no air was going back into caliper. The Bosch representative discussed a "gravity bleed" where they simply open the bleeders and allow the fluid to flow through the system. When the input torque to turn the wheels was again applied, they seemed similarly difficult to turn. Later, after the initial heat soak that occurred immediately after parking had cooled some, the wheels seemed easier to turn. The wheels were removed and the rotors were examined for overall condition, corrosion, transfer of lining material (indicating high heat), or bluing. The right rear rotor showed some pitting and transfer of lining material. The piston boots looked intact (with limited vision access).

The wheels were reinstalled and a Snap-On infrared pyrometer was secured for the second test drive. A dealership service manager drove the vehicle on a 15-minute stop-and-go commercial roadway and looped back to the dealership. The vehicle was stopped at one corner of the dealership and the Workhorse representative crawled under the vehicle to find the temperatures of the inner rotor surface with the IR pyrometer. The ambient temperature was 75°F and the brake temperatures were RF: 185°F, LF: 180°F, LR: 185°F, and RR: 305°F. It seemed that something was still hanging up in the right rear brake system. The vehicle was driven again along the same route with more braking especially toward the end of the drive. The Bosch representative advised the driver "don't drive like you have a CDL this time", meaning to drive more like we had seen the owner with crisper starts and stops. The vehicle had some pulling when the driver took his hands off the steering wheel, and after stopping at a traffic light, the vehicle would not roll forward under idle conditions after the brake was released. The vehicle was driven into the shop and again raised on jack stands. The temperatures were RF: 265°F, LF: 370°F, LR: 450°F, and RR: 300°F. There was more left-to-right variation at both axles and the rear axle hot brake had switched sides. The wheels again had the unexpected amount of drag, but this was not a documented test and none of the participants had tried this procedure before. This drag may be a normal situation. The bleeder valves were opened one at a time and the right rear caliper again had a pulse of fluid, but less than before. The torque required to turn the wheels was still more than anticipated. The calipers were struck with a plastic-tipped mallet and seemed to turn easier.

The vehicle was reassembled and driven along the same route. The aggressiveness of the drive was slightly increased compared to the last run. The temperatures when brought into the shop were RF: 345°F, LF: 341°F, LR: 360°F, and RR: 403°F. There were only minimal fluid dribbles when the bleeder valves were opened. The mallet on the caliper did not seem to change the drag until the technician struck directly onto the mounting bolts for the slide pins. Next, the right rear caliper was removed (with the brake line intact) and the pins were inspected. The caliper was reinstalled without the brake shoes and the caliper was found to slide with very little force (50 lb is the upper limit, and it took less than an estimated 10 lb). The pins were then torqued in reverse order (trailing then leading) and there was no change. The troubleshooting had started with a trend, then reversed, then disappeared.

The next morning the group met and discussed ideas. The Bosch representative proposed the theory that a heat soak occurred after the vehicle was stopped and the caliper, rotor, linings, and lining back plates increased in dimension slightly. The square cross-section piston seals, which provide the "spring" force (through distortion into a specially shaped cavity in the caliper land groove), could not pull the pistons

back any further than the starting point. So, during our shop test the drag increased, held, and then decreased simply due to the predictable thermal expansion of the components due to the heat soaking after stopping. This would not be a problem in normal use since the normal forces of rotor run-out, rotor deflection from vehicle turns and bumps, and other pavement variations would help push back the pistons within several hundred feet of driving after a thermal soaking stop.

A telephone conference had been arranged with Bosch to discuss the drag on the wheels after the vehicle was driven, and Workhorse Engineering was trying to get a vehicle and perform the same sequence to test another chassis. The telephone conference with Scott "Wisthull" (sp?) referenced fade and recovery test temperatures, and it was agreed that the initial heat soak could cause some temporary drag. He had also found some old tests and reported that on 245/70R19.5G tires with a brake temperature of 375°F, a rotational drag of 33 ft-lb had been measured. He also said that since the right rear ABS wheel speed sensor was melted, the hydraulic seal could have lost some of the retraction capability that was initially present in a new seal. Since the owner reported the brake pedal dropped, the fluid could have boiled. Their chemist could determine the boiling point of the fluid, but not if boiling had occurred. There was also some discussion on the predictability of friction coefficients. In some temperature ranges, the coefficient of friction is very predictable and in some ranges it may not be, which could explain the brake pull noticed on one test drive. The temperature ranges and water absorption of DOT 3 and 4 was discussed as well as the condition of the piston boots. The boots had looked ok; however, Wisthull said that only flame or direct boot-to-brake-shoe contact would cause a boot to look ashen or burnt. The towing of a Honda CRV without auxiliary brakes was discussed and dismissed as not a factor. Ideas were requested on how pressure could be trapped at one rear corner. The VRTC representative suggested a collapsed flexible hose or an ABS unit that does not operate as expected (as in a previous case due to lipseal flash). The torque order of the pins was discussed and Wisthull replied that it may or may not make a difference. Walt Stringham had performed tests and showed that drag could occur if the pins were torqued in the wrong order and it was better to torque in the suggested order. The peers were briefly mentioned with Ford 2008 "heavy" chassis 24,000/26,000 lb vehicles using the same TRW (Kelsey-Hayes) ABS system and Bosch ZOHT brakes. It was also discussed that the Ford had 73-mm calipers on the front and 66-mm calipers on the rear with cooling vent ducts to the front rotors. The teleconference was concluded. The Workhorse representative reported that his Engineering Group had warmed the brakes on a W-22 chassis, raised the vehicle, and found the force to rotate the wheels was "very low".

Next, the group discussed the steps to be completed before splitting up in the afternoon. The group list was:

- Trace all ABS wheel speed sensor signals to the proper corner with Tech2
- Trace hydraulic brake lines from master cylinder to the wheel ends by hand
- Remove/inspect all wheel speed sensors to insure none had partially melted
- Remove and replace the right rear wheel speed sensor
- Test drive the vehicle on the freeway for approximately 30 minutes
- Capture the continuous sensor data on the Tech2 during the test drive
- Remove the right-rear caliper and inspect, remove the dust boots and inspect again
- Capture the fluid leaked from the flexible hose when the caliper was removed
- Cycle the ABS with the Tech2
- Flush the right rear brake line and capture the fluid

- Remove the right rear flexible hose and blow compressed air through the hose on to white paper to inspect for dislodged debris
- Download the Tech2 data for later analysis

The hydraulic lines from the master cylinder to the wheel ends were traced and inspected. Three wheel speed sensors were inspected, photographed, and found to be in good condition, as shown in Figures 2 to 5, and the right rear wheel speed sensor was replaced. The wheels were turned one at a time while monitoring with the Tech2 and it was found that each wheel speed sensor connected to the proper wheel. The Tech2 found three error codes that were not present previously. The codes were 27, 31, 32, and 37. The Code 27 reports "erratic left front wheel speed sensor", Code 31 reports "right rear sensor open or short" (seen previously), Code 32 reports "right rear circuit signal missing", and Code 37 reports "left rear excessive variation in signal". These new codes could have been set while turning the wheels one at a time by hand or from removing the sensors for inspection.

The vehicle was driven for approximately 30 minutes on the freeway, then stopped to refuel. The inner surface of the brake rotors was measured at RF: 130°F, LF: 137°F, LR: 134°F, and RR: 179°F (possible light drag) and were considered mostly normal. The ABS light was off during this drive. The continuous data was captured by the Tech2. The vehicle was driven back to the dealership, with some aggressive stops near the end, positioned in the work bay. The inner rotor temperatures were found to be RF: 313°F, LF: 265°F, LR: 282°F, and RR: 319°F. After the vehicle was raised, all wheels could be turned by hand with some force. The brake line nuts at the master cylinder were loosened (a step in the International troubleshooting book that had not been tried) and only a dribble came out of each line. The right rear caliper was removed and the brake fluid that leaked out of the line was captured. The caliper piston accordion boots were inspected and found to be cracked and burnt, as shown in Figures 6 and 7. The boots were lifted out of position and the top of the seal land was found to be covered with the factory installed lithium grease and free of corrosion, as shown in Figure 8. The ABS was cycled once with the Tech2, and then error codes prevented further cycling. Brake fluid was flushed and collected at the right rear wheel. The right rear flexible hose was removed, as shown in Figure 9, and compressed air was blown through the hose onto white paper. No debris was found.

Recommendations: These vehicles are difficult to locate while they are experiencing the problem, and the owners are reluctant to lease the expensive and fragile vehicles for testing. This inspection showed a transient situation that could make leasing, transporting, and attempting to test a vehicle at VRTC to be an expensive exercise with limited results. Since the Workhorse and Bosch representatives were providing forthright information during the troubleshooting of this vehicle, continued participation in the joint Workhorse/Bosch field inspections is the best solution to resolving this problem.

Peer groups often assist in explaining behavior of systems under investigation. In this case there are multiple platforms that use, or do not use, several of the same components. A partial list includes the W-24 (24,000 lb) chassis that does not have warranty claims of thermal events, a new 2008 "heavy" Ford chassis that uses the Bosch calipers and the TRW ABS unit and does not have warranty claims, and International vehicles that use the Bosch brake calipers, flexible brake hose, and possibly hose fittings and crimp design and do not have warranty claims. The make, model, and similar equipment list of these vehicles should be compiled and sorted to

spot trends in the data. The International RVs may have a warranty trend that is different from the overall International production since the RVs daily and yearly usage patterns are unique. Peer component breakdowns and possibly peer letters should be issued.

Daniel G. Pearse

Dan Pearse

Vehicle Safety Engineer
Defects Analysis Group
Vehicle Research and Test Center

Photographs

Figure 1 - View of the Complaint Vehicle during Test Drive with the Owner
Figure 2 - The ABS Sensor from the Left Front Wheel Appeared to be in Good Condition and had not been Overheated
Figure 3 - The ABS Sensor from the Right Front Wheel Appeared to be in Good Condition and had not been Overheated
Figure 4 - The ABS Sensor from the Left Rear Wheel Appeared to be in Good Condition and had not been Overheated
Figure 5 - The ABS Sensor from the Right Rear Wheel was found Melted and was Hanging by the Sensor Wire Outside of the Metal Housing
Figure 6 - After the Right Rear Caliper was Removed from the Slide Pins, the Damaged Boot on the Leading Piston was Visible
Figure 7 - The Trailing Piston Boot was also Damaged
Figure 8 - After the Piston Boots were Removed from the Right Rear Caliper, the Undamaged Seal Lands were Visible
Figure 9 - The Right Rear Caliper Flexible Hose was Removed and Compressed Air was Easily Passed through the Hose

Acronyms

ABS	Antilock Brake System
CDL	Commercial Driver's License
DOT3	brake fluid certified to meet Department of Transportation requirements No. 3
DOT4	brake fluid certified to meet Department of Transportation requirements No. 4
EBC	Electronic Brake Control
EHCU	Electronic-Hydraulic Control Unit
°F	Fahrenheit scale of temperature measurement
GCWR	Gross Combined Weight Rating (including trailer)
GVWR	Gross Vehicle Weight Rating
GVWRF	Gross Vehicle Weight Rating Front axle
GVWRR	Gross Vehicle Weight Rating Rear axle
IR	Infrared pyrometer
LF	Left Front
LR	Left Rear
MAF	Manifold Air Flow sensor
ODI	Office of Defects Investigations
RF	Right Front
RR	Right Rear
RV	Recreational Vehicle
SES	Service Engine Soon
TAC	Throttle Actuator Control
Tech2	GM Service Tool
TPS	Throttle Position Sensor
TRW	manufacturer of auto/truck parts
VIN	Vehicle Identification Number
VRTC	Vehicle Research and Test Center
VRTC-DA	Vehicle Research and Test Center - Defects Analysis Group

Figure 1 - View of the Complaint Vehicle during Test Drive with the Owner

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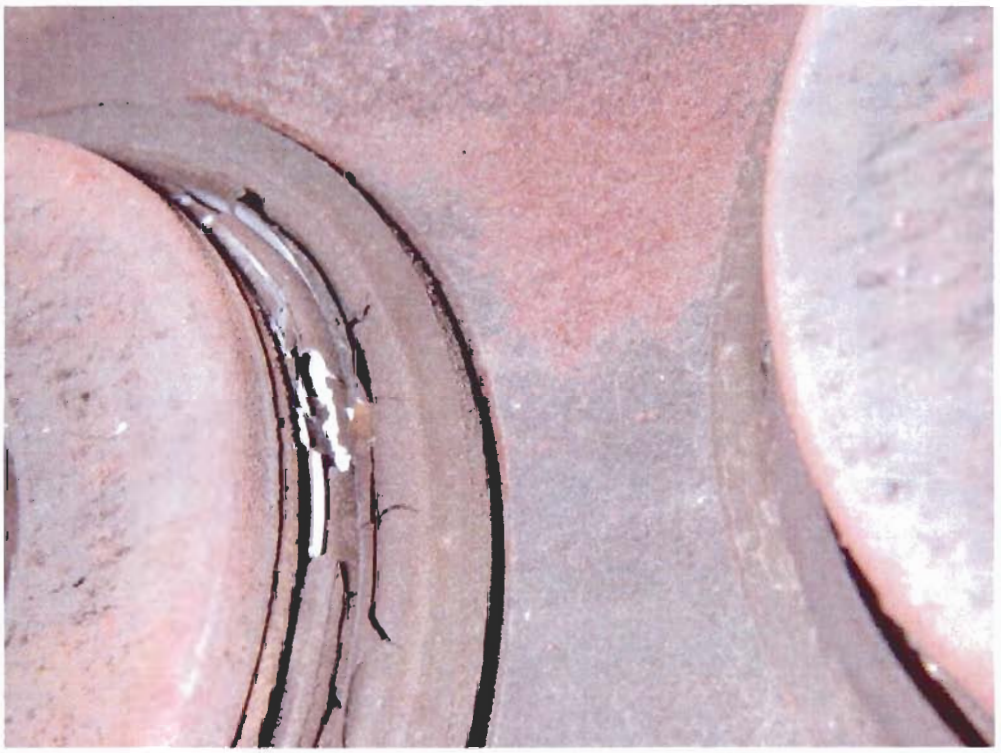

Figure 6 - After the Right Rear Caliper was Removed from the Slide Pins, the Damaged Boot on the Leading Piston was Visible

Figure 7 - The Trailing Piston Boot was also Damaged

Figure 8 - After the Piston Boots were Removed from the Right Rear Caliper, the Undamaged Seal Lands were Visible

The white substance is the Lithium grease that is installed to help displace moisture from the seal land area.

Figure 9 - The Right Rear Caliper Flexible Hose was Removed and Compressed Air was Easily Passed through the Hose