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Effects of Evidence Spoliation on Forensic Engineering Analysis of Alleged Brake Servicing Defects

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Abstract

A forensic case involved an allegation of defective minivan brake repairs. On a wet two-lane road, the minivan left the road while stopping, and impacted a telephone pole. The plaintiff driver's complaints implied a dragging brake, and the plaintiff's expert reported a bent lower caliper bolt. This forensic investigation involved instrumented exemplar analysis of the effects on caliper drag that could be caused by a bent caliper bolt. The investigation methodology was chosen (in part) based on significant evidence spoliation on the part of the plaintiff's expert. This paper will also discuss the effects of the spoliation and resulting limitations on the scope of the analysis.

Keywords

Brake, caliper, spoliation, forensic engineering

Introduction

In November of 2008, the plaintiff was driving a "loaner" pre-owned 1999 Plymouth Voyager minivan provided by a vehicle reseller while the plaintiff's car was being serviced. On the second day of the plaintiff's use of the minivan, the plaintiff was driving in rainy daylight on a straight two-lane road with a posted 45-mph speed limit. When approaching a vehicle waiting to turn left into a driveway, the minivan left the road — the plaintiff recalled only that she applied the brakes when approaching the stopped car. The minivan went onto the right shoulder and across a residential lawn, rotating about 80 degrees clockwise about a vertical axis, eventually stopping when the driver's door impacted a telephone pole. The plaintiff and a passenger were injured (**Figure 1**).

Figure 1
Impact damage to minivan.

The plaintiff stated in her deposition that upon receiving the "loaner" minivan from the dealership, she noticed that brake application caused the vehicle to pull to the right at speeds under 35 mph. She testified that she brought the condition to the attention of the reseller and that the service manager told her the minivan had recently had brake work done — and that the problem would go away with use. The plaintiff testified that she left the dealership and continued to experience pulling to the right (to varying degrees) upon brake application, though the vehicle tracked straight otherwise. She also reported that the brake pedal went close to the floor during operation.

Discovery documents revealed that the minivan indeed had new front discs and front pads installed just prior to the plaintiff's use of the vehicle. The service manager had no recollection of being alerted to the pulling condition by the plaintiff.

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The dealership's insurance company hired an expert to inspect the vehicle prior to receiving notice of pending litigation. That expert inspected in January 2009 and reported no causative problems. During this inspection, the wheels and rear brake drums were removed. According to this expert's report, due to vehicle damage, the brake pedal was not operated. The wheels and drums were replaced following the inspection.

The plaintiff hired an expert to inspect the vehicle, and he conducted inspections in August and September of 2011. According to his deposition testimony, in his first inspection, he did not find any notable issues with the brakes. He was also able to depress the brake pedal and found that the vehicle had "full pedal," which typically means that the brake pedal was not noticeably soft nor would the pedal slowly sink under sustained foot pressure. The plaintiff's expert's testimony went on to say that he was instructed (by his retaining attorney) to do another inspection and disassemble components in order to try and find problems. His second inspection was conducted alone, without participation by (or notice to) other potentially involved parties. During this second inspection, he removed the front brake calipers, disconnected the hydraulic brake hoses to the calipers, and took custody of these parts. During the removal of the right front caliper, the plaintiff's expert reported discovering that the passenger's side (right) lower front brake caliper bolt was bent.

The plaintiff's expert alleged that the incident was due to this bent lower caliper bolt causing brake pulling upon application. The subject minivan utilized single-piston sliding front brake calipers that have two bolts (**Figure 2**). In such designs, the caliper piston is inboard and (when actuated) presses the inboard brake pad against the disc. This piston force simultaneously causes the caliper to slide axially along lubricated cylindrical "slider" bushings (**Figure 3**), in turn causing the outboard features of the caliper to pull the outboard brake pad against the disc. The upper and lower caliper bolts locate and retain these lubricated cylindrical bushings. Over time, improperly maintained sliding caliper assemblies may bind or drag if the caliper itself cannot slide freely on the lubricated cylindrical bushings. Additionally, since the piston's force application is offset from the cylindrical bushing axes, a bending load is imparted to the cylindrical bushing/caliper interface. The bushings often (including on this minivan) have a rubber "bellows" type boot around them to reduce the ingress of contaminants into the bushing grease. It can be seen from **Figures 2** and **3** that if one of the caliper bolts were significantly bent, it could causing binding or dragging of the caliper in use.

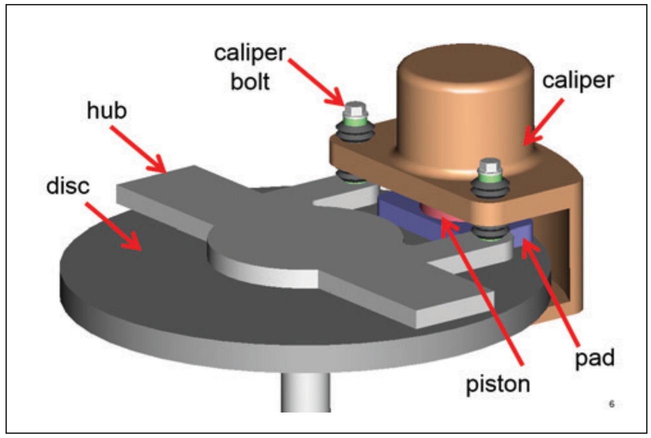

Figure 2
Simplified representation of sliding brake caliper.

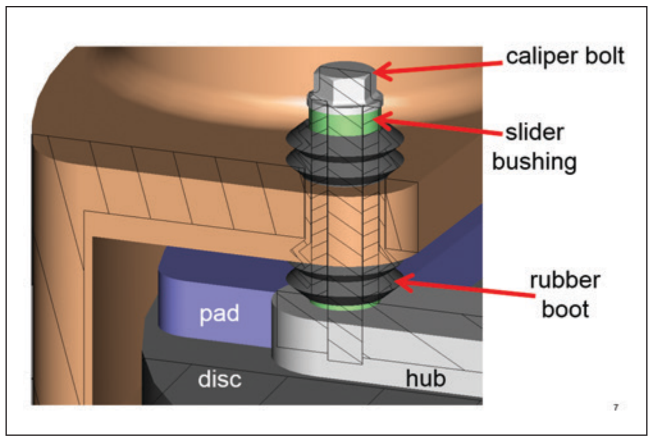

Figure 3
Close-up of caliper bolt area.

The plaintiff's expert alleged that the lower caliper bolt had been bent by the vehicle dealership when it was replacing the front brake discs and pads. This was based on his experimenting with an exemplar steering knuckle, brake disc and caliper wherein after removing one of the two caliper bolts the caliper could be rotated (about the other bolt) sufficiently "out of the way" to replace the brake disc. In doing this, it would be possible to bend the remaining caliper bolt during the manipulation of the caliper and brake disc — this is what the plaintiff's expert alleged the dealership had done. Of interest was that the plaintiff's expert based this allegation on his experimentation with the steering knuckle, disc and caliper from a Chevrolet Cavalier sedan. He did not try this on Plymouth Voyager (or equivalent Dodge or Chrysler) minivan components.

Recalling, the testimony by the plaintiff was that the brake pedal would go nearly to the floor in use. The plaintiff's expert claimed the bent caliper bolt caused this condition because the brake caliper dragged and heated up the brake fluid, which "thinned out the viscosity" of the brake fluid.

It is noted that the analysis conducted in this case was focused on addressing the assertions of the plaintiff's expert. The spoliation of evidence by the plaintiff's expert eliminated the ability to conclusively determine the cause of the incident, so potential mechanical factors that might have otherwise been evaluated were not, in fact, evaluated. Additionally, the extensive incident-related damage to the vehicle and accumulation of corrosion while sitting on the salvage lot further reduced the ability to investigate operational factors that might otherwise have been of interest.

Preliminary Analysis

In a scenario where a vehicle pulls to the left or right under braking, it can be due to problems in the braking system, suspension, or tire pressures. There was no record of the tire pressures either before or after the incident, and — due to the vehicle damage — it would have been difficult to evaluate any contribution of loose suspension joints, alignment issues, etc. The plaintiff's expert focused on the brakes (specifically, the front brakes).

Potential causes of brake pulling

1. Brakes pulling to one side can be caused by air or vapor in the hydraulic brake lines. With vehicle brakes, a specific depression of the brake pedal will result in a specific brake force response, due to the fact that hydraulic fluid is incompressible. Air or vapor in a hydraulic system, however, is compressible, and brake pedal motion is "lost" in first compressing the air/vapor before significant brake force response occurs at the disc brake caliper or drum. This condition of air/vapor in brake lines is commonly known to cause reduced brake performance and a potentially "low pedal" that must be depressed further than normal for a given brake response — both of these are conditions reported by the plaintiff. If one side of the braking system is working significantly better than the other side, the vehicle will pull in the direction of the stronger brake. Once air/vapor accumulates in the brake lines, it may migrate to areas where it has a greater or lesser effect on braking performance. The plaintiff's expert, in disconnecting the front brake lines, eliminated the ability to determine if air/vapor accumulation was a factor in the incident.

   a. Causes of air in brake lines include leaks, low brake fluid reservoir level, and failure to bleed the system after disconnecting brake lines for servicing. Vapor in the brake lines is due to overheating of the brake fluid. Water vapor can also accumulate in brake lines due to the hygroscopic nature of many types of brake fluid (which contain alcohol); the absorbed water vaporizes at a lower temperature than the brake fluid. Addressing these individually:

      i. Neither the insurance company's expert nor the plaintiff's expert had noted any brake fluid leaks or a low brake fluid reservoir level.

      ii. It was possible that the brake lines had been disconnected by the dealership during servicing, which could have introduced air, but there was no testimony indicating this had been done. Manufacturers typically recommend bleeding fluid out of the brake system during pad replacement (when resetting the caliper piston), but typically this is done simply by opening the caliper bleed screw. Another method often used during pad replacement is to simply reset the caliper piston and let the brake fluid backflow into the reservoir — this does not involve opening the brake lines to air ingress. As an exemplar inspection was planned, one task was to check to see if disconnecting the front brake lines was necessary in order to change the brake pads and brake discs.

      iii. Excessive heat can build in the brakes with extended hard use or due to the driver "riding" the brakes; this is often manifested by bluing and fine cracking of the disc surface, as well as an "ashen" appearance to the outside of the caliper. Neither of these conditions was noticed in the two inspections, though the brake discs had been recently replaced. Excessive heat can also result from a dragging caliper that does not fully release.

b. The plaintiff's expert's assertion that the low brake pedal was caused by hot and less-viscous brake fluid was judged irrelevant to the analysis. Viscous or less-viscous fluid is still incompressible, and there are no studies showing any pattern of less-viscous brake fluid affecting pedal height. Brake fluid viscosity is an issue in the valving of antilock brake system (ABS) modules, but this vehicle did not have ABS.

2. Brakes pulling to one side can also be caused by a binding/dragging caliper or, for rear drum brakes, a sticking wheel cylinder. In these scenarios, the brake actuator does not move freely due to mechanical interference caused by corrosion, usage of mismatched components, improper assembly and poor workmanship, or deformed components.

   a. Inspection of the subject caliper components did not reveal undue corrosion overall. The passenger's side (right) front caliper was the primary focus as it was this caliper that had the bent lower bolt (see **Figures 4** through **7**). Note that regardless of where a bending load would have been applied along the bolt head or the slider bushing, the bending would manifest itself at the "weak point" of the threads, due to the stiffening support provided by the slider bushing. The lower slider bushing's boot was damaged, but the surface of the bushing did not show any corrosion. Note that by design the bushing is completely "suspended" within the rubber boot, and does not contact the caliper casting directly. Of interest, **Figure 8** shows an impact/wiping deformation area observed on the inboard end of the bent slider bushing; the most likely cause was judged to be that a floor jack was improperly placed on the bushing following manual retraction of the rubber boot. But such an action would be inconsistent with typical or effective shop practices. Regardless, the cause or time frame of this deformation remains unknown.

   b. There was no evidence that mismatched components were used in this area of the subject minivan.

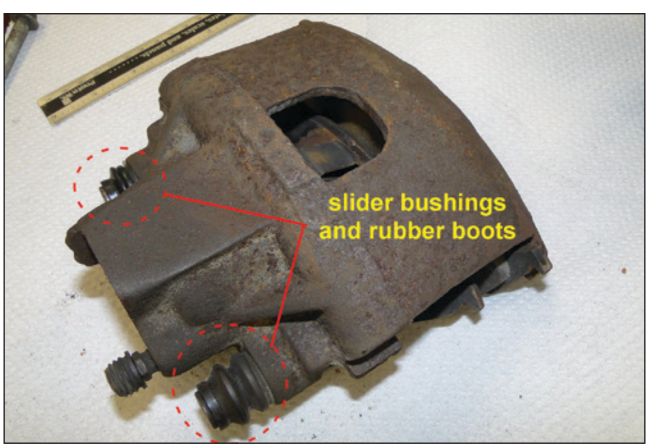

Figure 4
Right caliper.

Figure 5
Lower slider bushing and boot.

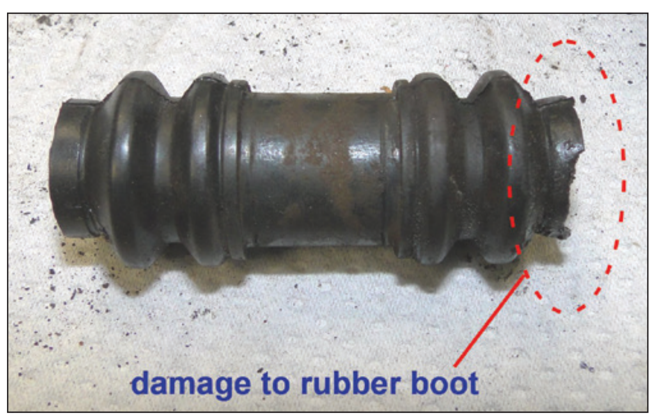

Figure 6
Damage to lower slider's rubber boot.

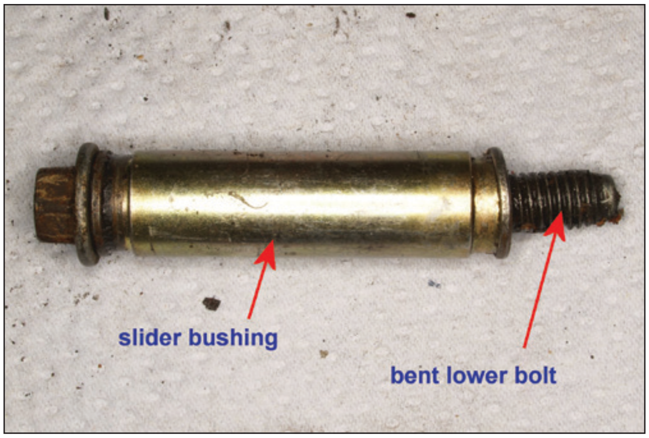

Figure 7
Lower slider bushing and bent bolt.

Figure 8
Impact/wiping marks on inboard end of slider bushing.

c. The question of improper assembly and poor workmanship could pertain to the question of how the subject lower caliper bolt became bent. One of the plaintiff's expert's allegations was that the bolt was bent by undue forcing of the caliper during service. It was decided that the exemplar minivan would be used to analyze this.

d. The subject lower bolt also could have been deformed by some external force application unrelated to the dealership's servicing. For example, the vehicle had been stored at an auction yard for years following the incident. This auction yard (like many) moves vehicles around through the use of large wheel loaders equipped with long forks that the drivers basically shove under the vehicles to pick them up. **Figure 9** shows (on an exemplar minivan) how the lower caliper bolt could have been readily contacted by fork tips; additionally, there was a fresh scrape mark on the front surface of the right front lower control arm (below and behind the lower caliper bolt) in photographs taken by the dealership's expert two months after the incident. Consistent with this scenario, it is also of note that not only the lower caliper bolt was deformed, but the face of that bolt's slider bushing (that contacts the suspension upright) also showed deformation consistent with a bending force being applied to the bolt (or bushing) while it was in place on the vehicle (**Figure 10**). It is not conclusively known, however, what the rotational orientation was of the bend in the bolt (and slider bushing) preceding their removal by the plaintiff's expert, as he had taken few photographs of the components during disassembly. Low-resolution zoomed-in portions of the few digital images taken by the plaintiff's expert appeared to show that the bolt was bent vertically up, but this was not conclusive.

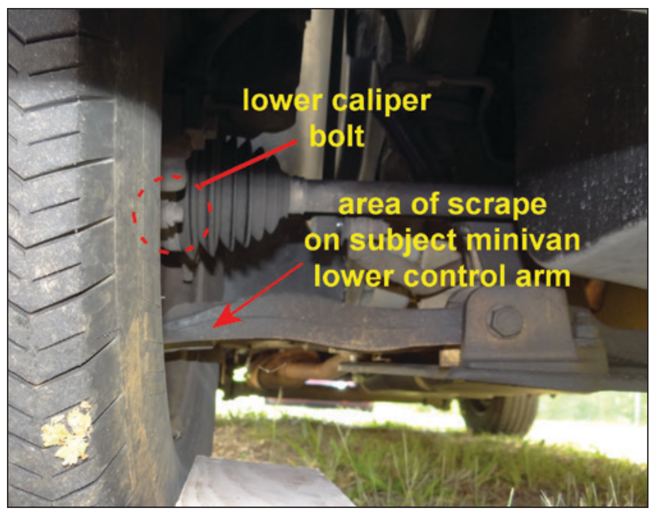

Figure 9
Accessibility of lower caliper bolt to fork tips (exemplar).

Figure 10
Deformed end of lower slider bushing.

Test Configuration

There were three hypotheses tested in this investigation:

1. It may have been necessary to remove the brake line from the caliper in order to replace the pads and brake disc during servicing.

2. It may have been possible to attempt to remove the brake disc with only the top caliper bolt removed (in servicing), which could, in turn, have led to bending of the lower caliper bolt.

3. The bent lower caliper bolt could have caused the caliper to stick or drag in use.

   a. A binding/dragging caliper could have caused brake overheating and hot brake fluid vapor buildup in the brake lines.

   b. A binding/dragging caliper could have caused brake pulling.

The testing plan for these hypotheses involved:

1. Evaluating the ability to replace the brake pads and disc without disconnecting the brake line.

2. Evaluating the ability to remove the brake pads and disc with only the top caliper bolt removed.

3. Testing the effect of the bent caliper bolt on brake force response through instrumented measurement of brake pedal application/release force + timing versus caliper actuation/release force + timing.

   a. This analysis involved depressing/releasing the brake pedal to see what the actuation/release response of the brake caliper would be. It was decided that obtaining repeatable data would require standardizing the speed and force of depressing/releasing the pedal, and pneumatics were chosen for this purpose. Though brakes will actuate without power assist, the subject vehicle had vacuum-assisted power brakes (as expected), so it was decided that the testing should involve a functioning power brake booster in the exemplar test vehicle.

   b. Two types of sensors were chosen for use in this force analysis:

      i. The application/release of brake pedal force was expected to be a "rapid" event, with impact spikes and other significant accelerations and decelerations occurring in less than 0.1 seconds. For this reason, it was decided to use a 500-pound capacity piezoelectric force transducer between the pneumatic brake pedal actuator and the brake pedal. This type of force transducer can capture data at a high sampling rate, but experiences rapid decay in its signal. Therefore, it was judged better suited to short-duration applications such as this (**Figure 11**).

Figure 11
Pneumatic brake pedal actuator/sensor apparatus.

      ii. The measurement of brake caliper piston response (through output force) was expected to be a "slower" event, potentially greater than 0.1 seconds, given that it was lagging/dragging of the caliper response that was being measured. For this reason, it was determined that a piezoelectric force transducer would not be appropriate due to signal decay. A 5,000-pound capacity strain-gauge type load cell was used for this application. These types of sensors are less compatible with high sampling rates, but are better at tracking force changes over time. These sensors took the place of the outboard brake pads and were mounted to a large washer and indexing rod that fit within the cylindrical recess of the composite caliper piston. The thickness of the installed assembly was approximately .06 inches thinner than a new brake pad (see **Figures 12** through **15**). Through this apparatus, the inherent self-retracting behavior of the caliper piston seal was not affected.

c. A calculation error led to the decision to use the 5,000-pound capacity load cell; it would have been better to use a 20,000-pound capacity cell due to the force multiplication that the exemplar vehicle's power brake system produced. As it was, pneumatic brake pedal force application was limited to 25 pounds in order to avoid overloading the 5,000-pound load cell. Time constraints precluded re-doing the test with a higher capacity load cell. It was decided that (due to the small operational deflections inherent in caliper application) dragging/lagging of the caliper response would likely happen at these lower application forces as well. During testing, the running engine's vacuum was periodically checked to ensure that it remained within factory specifications.

d. The pneumatic system utilized a large air reservoir so that repeated brake pedal actuation would not cause a significant drop in cylinder input pressure. A lever-actuated pneumatic valve was used to apply the pedal actuation force.

e. The actual force magnitudes measured by the sensors were judged less important than the consistency and rapidity of response of

Figure 12
Mounted strain gauge.

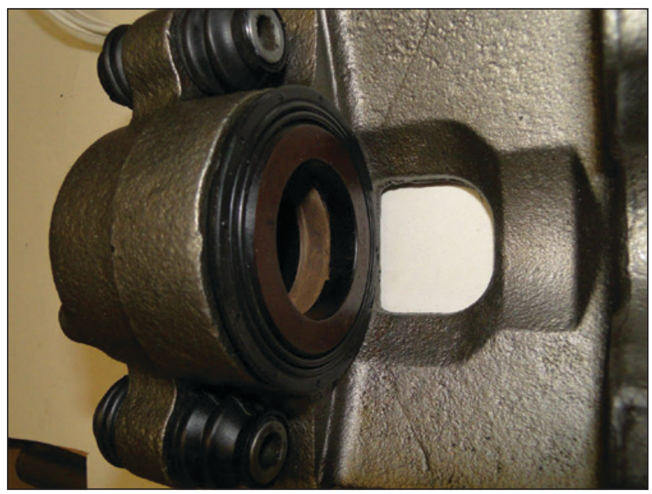

Figure 13
Exemplar caliper showing composite piston.

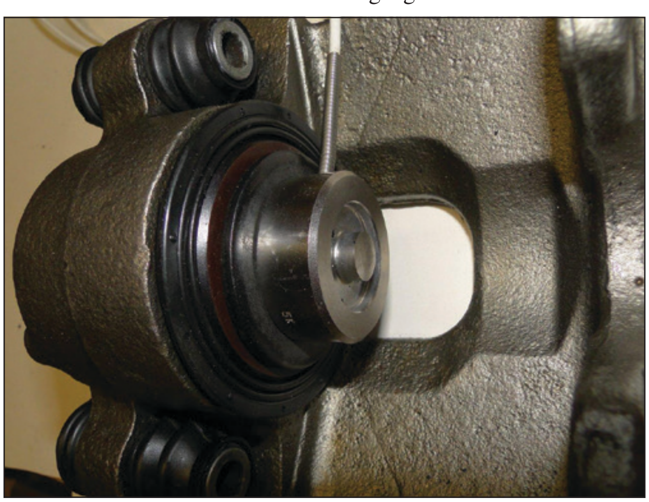

Figure 14
Strain gauge installed in caliper.

Figure 15
Instrumented caliper mounted on exemplar vehicle.

the brake caliper piston to the brake pedal actuation and release. This was to be evaluated for a baseline configuration, and then for a configuration where the lower caliper bolt was manually bent by the author.

Test Results

1. It was not necessary or beneficial to remove the hydraulic brake lines from the front calipers in order to change the pads and disc. As such, it is not reasonable to expect that the dealership would have done so and introduced air into the hydraulic system.

2. It was not possible to remove the brake disc without unbolting both caliper bolts and removing the caliper. This counters the assertion of the plaintiff's expert that the lower caliper bolt was bent during the brake servicing by the dealership's attempts to remove the disc without removing the caliper.

3. The baseline evaluation provided usable data, showing a consistent force response of the caliper piston to repetitive pedal input. The sampling frequency was 1,000 Hz. Once the baseline was obtained, the head of each lower caliper bolt was bent vertically up to a total bend of approximately 6 degrees. The bolt was bent first through the use of a bar clamp and then (when the bar clamp proved inadequate) by lifting the vehicle (in effect) by raising a floor jack under the caliper bolt (**Figures 16** and **17**).

4. The data is summarized in **Figure 18**. Pedal input force is in the top charts, at both application (top left) and pedal release (top right). The "baseline" tests were before the caliper bolts were bent, and five data sets were taken. The caliper piston output force is shown at application (bottom left) and release (bottom right).

5. Observing the data, some comments can be made:

   a. Pedal application: Apart from the spike at initial pedal application (time ~ 0), when the plunger impacted the sensor, the pedal application took about 0.4 seconds, so perhaps a strain gauge sensor would have worked in this part of the apparatus. The decay of the piezoelectric sensor signal is apparent starting at about 0.42 seconds. The applied force did vary somewhat, even when the initial "bias" of the system (before t = 0) is taken into consideration. But this did not seem to translate into corresponding variability in the caliper output.

   b. Pedal release: The force dropoff at pedal release appeared to have a consistent plot profile. Again, there were minor differences in the before/after force, even considering the bias.

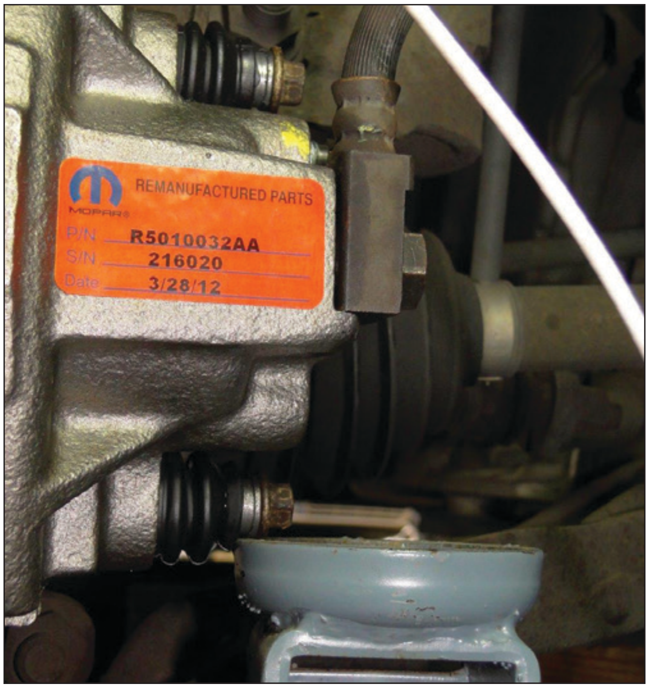

Figure 16
Bending bolt with jack.

Figure 17
Measuring amount of bend.

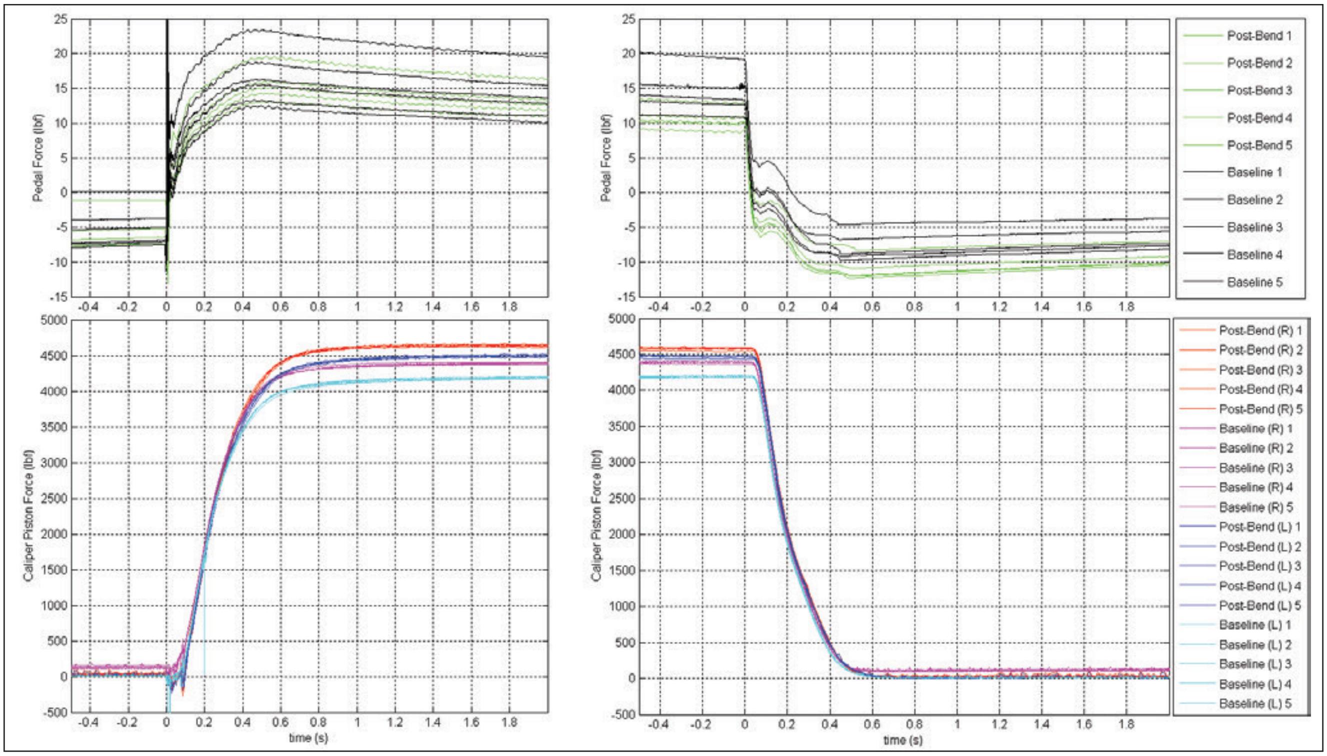

Figure 18
Test data summary plot.

c. Caliper response – application: The right side baseline and bent-bolt response curves were closer together than the left side, but in both cases there was more caliper force with the bent bolt than without. Each group of five traces appeared to be fairly consistent, despite minor variations in the pedal input force. And the force onset profile appears quite similar for all four sets of five traces.

d. Caliper response – release: In all cases, the caliper force release took no more than 0.03-0.04 seconds to occur. The "gentle" ramp down of forces after 0.04 seconds could be due to a combination of the sensor response and the elasticity of the caliper assembly. And in each trace, the force eventually goes to ~0 after 0.6 seconds.

e. Overall conclusions from this testing:

   i. The consistency of profile with each of the different plot traces appears to show that the apparatus and method provide usable results.

   ii. The bent bolt did not cause a significant comparative lag in either caliper force onset (upon pedal application) or release.

   iii. There did not appear to be residual caliper force (i.e., brake drag) due to the bent bolt, such that would cause overheating of the brakes and vaporization of the brake fluid.

Conclusions

Reviewing the plaintiff expert's assertions again, which were: 1) the dealership had bent the lower caliper bolt during servicing; 2) the bent bolt caused a low brake pedal; and 3) the bent bolt caused brake drag and pulling upon application, this investigation disproved those assertions at a general level — through the use of exemplars. However, because the plaintiff's expert unnecessarily disassembled the subject vehicle's brake components and opened up the hydraulic system, it is not possible to conclusively determine the cause of the subject vehicle's bent bolt, the effect it would have on the subject vehicle, or the potential contribution of air/vapor that might have been in the hydraulic lines. As such, it is not possible to conclusively determine the cause of the subject incident.

The author wishes to thank Erich Schlender, PE, for his invaluable assistance in this forensic analysis.