



THE NUMBER ONE DODGE/CUMMINS TURBO DIESEL RESOURCE

# The *Perfect* Collection



*A collection of "best of" articles from the TDR's staff of writers and members.*

# From the Editor

## THE “PERFECT COLLECTION”

In an editorial that talked about the TDR's 20 year anniversary, I mentioned that I really enjoyed reading the writers' recollections of their best articles.

I looked through their write-ups with an eye for nominating articles that I would want to include in a format similar to that of the Turbo Diesel Buyer's Guide, and title that book as “The Perfect Collection.”

What should be the criteria for inclusion in the Perfect Collection, what does that unassuming title promise the reader?

A quick look back to an article in Issue 56 (on fuel transfer pumps, it happened to be) will give you the angle. I wrote, “Perhaps we should emulate the country music singer David Allen Coe's efforts to write the perfect country music song by writing the perfect transfer pump article.” And, by golly, although I'm a modest guy, I'd say I did just that in Issue 56.

Now, TDR reader, which articles from the past would you say warranted my choice for the Perfect Collection? How about the following?

- Exhaust Brakes / Issue 71
- Exhaust Brake Valve Springs/Valve Spring Adjustment / Issue 54 and Issue 30
- Injectors / Issue 72
- Vibration Dampers / Issue 73
- Fuel Tanks / Issue 75
- Lube Oils / Issue 76
- Air Filters / Issue 80, 56, 59
- Third Generation Purchase Criteria / Issue 77
- Brake Systems / Issue 40-45, 50
- Fuel and Lube Oil Additives / Issue 64
- Death Wobble / Issue 74
- Truck Detailing / Issue 68
- Clutches / Issue 63
- Coolant / Issue 62
- My Truck Won't Start / Issue 81
- Lube Oil Filters / Issue 71
- G56 Rebuild / Issue 71
- Ram Automatic Transmissions/Issue 84 and 87
- The Cummins 6.7-liter Engine 2007.5-2012

So, TDR members, there you have it—a collection of articles that we can use, reference and share with others that have the desire to learn more about their trucks. As I added each article to the Perfect Collection I reread its contents to make sure it was timely and correct. Enjoy this new book, the “Perfect Collection.”



Robert Patton  
TDR Editor

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# Exhaust Brakes

ISSUE 71

## MOMENTUM VERSUS THE EXHAUST BRAKE

### A look at slowing things down

by David Magnoli

The theme of this issue is Momentum, and it is the perfect prompt as I had recently dealt firsthand with such force of motion and it made me realize how I have taken my exhaust brake completely for granted over the last several years. That is, of course, until it stopped working.

When I bought my 2001.5 truck it was a few years old and, for the most part, it was a stock truck that the former owner used to tow a 30-foot, bumper-pull travel trailer. That kind of weight can test the function of our brakes at any time, but when traveling on a long, steep downhill it becomes even more of an issue. Although the truck was stock in the power department, he wisely recognized that the addition of an exhaust brake was called for and added one to the truck. This being my first diesel vehicle, I was still getting used to the many differences between it and the gas trucks I had owned in the past, and I don't think I fully appreciated the exhaust brake fully at that time. I probably would not have gone out and bought one for myself, but after towing with it and using it pretty much all the time for the last several years, I would not want to be without it.

This past Fall when I was towing my trailer over the Sierra Nevada mountains, I had a problem with the electronic controller of my brake that caused the torque converter to not go into lockup when the brake activated, rendering the brake quite ineffective. Rolling down Tioga Pass towards the town of Lee Vining and US395 on that long steep descent, I really missed the ability to just release the throttle pedal, hear that reassuring growl, and feel the truck completely under control, slowing smoothly and confidently on any and all hills. After repairing the minor problem I had with the controller I decided to take a closer look at this simple, but very important, towing and safety accessory. Let me give you an overview of the exhaust brake that is used on the 5.9-liter engine from years '89 to '07. The '07.5 and newer 6.7-liter engines use a sliding vane in the turbocharger to create exhaust back pressure. Issue 70, pages 46-50, has the details for the 6.7-liter owner.

### Exhaust Brake Principle of Operation

The reason we even have the need for an exhaust brake lies in one of the basic differences between a gasoline and a diesel engine. In a gasoline engine there is a throttle plate that closes off the intake air when the accelerator is released. When the pistons move downward on the intake stroke, they pull against the closed throttle and cause a vacuum to be created in the cylinder, slowing the engine by this resistance. Because of the closed intake, there is very little air in the cylinder on the following compression stroke so that the rebound of compressed air against the downward traveling piston is minimal. Because of this there is an overall slowing effect on the engine.

A diesel engine has no throttle plate and air is open to the atmosphere on the intake side, allowing it to be freely drawn into the cylinders whenever the pistons move down on the intake stroke. When the fuel pedal is released and the fueling stops, the engine freewheels, becoming a very large air pump with a minimum of any intake or exhaust resistance, thereby offering nothing but internal friction and the service brakes at each wheel to slow the vehicle down.

This leaves us at a disadvantage when compared to gas truck owners in a downhill situation because they have engine compression going for them, and along with proper downshifting they can more effectively keep the vehicle speed in check than we can, saving the service brakes from overheating and fading. But all is not lost in this for the diesel pickup crowd, for we do have a very easy and even more efficient solution to our diesel's lack of braking resistance. It lives over on the exhaust side of things.

An exhaust brake is, in its simplest form, nothing but a valve that closes off the exhaust when the throttle pedal is released, a mechanical potato-up-the-tailpipe as it were. It is often referred to as a butterfly valve but, in truth, it is a one-piece, round disc on a central pivot-arm that rotates within a close-fitting housing. With the potato-up-the-tailpipe turned on, the exhaust cannot escape and back pressure builds in the exhaust system. The engine is working against itself and, since it is directly coupled to the drivetrain (a manual clutch or an automatic with a lock-up torque converter), the vehicle slows down. The faster the engine turns, the more backpressure is created, and therefore the more braking effect is felt. But that compressed exhausted air cannot be completely blocked off, it has to go somewhere in a controlled manner so that the engine is not damaged, while still allowing the brake to do its job, and this can be accomplished in a number of ways.



## Exhaust Brakes for '89-'07 Engines

There are several different brands of brakes available to us and they each use a different method of safely controlling and bleeding off of exhaust back pressure. Some, like Cummins/Jacobs, the Banks Brake on my truck, or early design Pacbrake units, use a fixed-size orifice in the butterfly valve that permits a measured amount of gas to escape down the tailpipe, but still allows enough compression of the exhaust gas to slow the engine effectively. This type of brake works best at higher engine RPM because it offers a set resistance determined by the size of the hole in the valve. At a higher engine speed, there is more backpressure and as such the brake resists more, but as this backpressure falls off with slower engine speeds, the fixed-size orifice in the butterfly allows that reduced pressure to bleed off more freely, resulting in a loss of slower-speed braking.

Others, like the BD brake, use a solid butterfly that is spring-mounted and regulated so that it varies the opening slightly as the pressure increases, bleeding off the needed amount of gas while still maintaining the optimal backpressure for a given RPM. As the RPM and pressure drop, the valve closes more completely, giving a more consistent braking effect as the engine and the truck slow down. This type is said to be more effective at lower engine RPM than the fixed-orifice type because it adjusts the bleed-off in a varying amount to match the pressure, giving better low RPM performance. Pacbrake's newest design uses a combination of these last two methods, with a fixed-sized orifice covered by a spring-mounted flap that does essentially the same thing by varying the orifice size to offer a variable-pressure braking effect through a wider RPM range.

When activated in the cold warm-up mode at idle, a loud hissing can be heard emanating from the exhaust tailpipe as the hot exhaust gasses are forced through the restricted brake butterfly. This is noticeably louder if you happen to have a straight exhaust. When activated while driving, it lets you know it is working by the smooth, deep-toned exhaust growl it generates as it does its job.

Regardless of which method is used to increase the backpressure, once the brake is closed and building pressure, all the exhaust paths in the head and the manifold system are exposed to this high pressure. Although not an issue on the newer 24-valve trucks, the older 12-valve trucks will need to have the exhaust-valve springs changed out to 60 pound springs to keep these forces, which are now on the back side of the exhaust valves, from opening these valves when the exhaust manifold is pressurized by the closed brake. You can get by without changing springs (the '89 to '98 12-valve engines were equipped with 35psi springs) if you use a brake with diminished capacity so as not to exceed the strength of the stock springs. These brakes usually just have a larger hole in the butterfly to allow less backpressure, but that will also result in less braking force because you are limited to building only 35psi of back pressure. For the 12-valve owners that may be considering an exhaust brake and the possibility of changing the exhaust valve springs there is an excellent why-for, how-to, what-if article in TDR Issue 54, pages 30-36. Check it out on the TDR web site's magazine archives.



**The Banks Brake on my truck is typical of turbo-mount brakes, replacing the stock transition elbow that connects the turbocharger to the downpipe. Being under the hood makes them less exposed to the elements than the inline models and also makes installation a simpler, bolt-on procedure. Mounting close to the engine also keeps the run of hoses to a minimum with less chance of damage. If you have twins or a non-stock single turbo though, this type is not an option.**

The brake's cast-iron or stainless steel butterfly valve is mounted in a very close-fitting, machined cast-iron housing that attaches to the exhaust system in one of two places, depending on the method preferred. Most manufacturers offer both types to accommodate any owner's preference. The first type is mounted directly on the exhaust side of the turbo, replacing the cast-iron elbow that forms the transition between the turbo and the downpipe on a stock truck. This is usually a bolt-on system that is supplied with a new downpipe and is a fairly simple installation. I have this style on my truck and the only thing that can be considered a negative about it is that it limits the type of turbo you can use. If you wish to use anything other than a stock-type turbo, such as twins, or a high-performance single, you will have to go with the second type of exhaust brake installation.

This second type of installation is an inline brake and it can be mounted anywhere on the exhaust, usually after the downpipe, but the closer to the turbo the better so as to reduce the volume of air that has to be compressed in use. Mounting further down the exhaust system would result in a delay in activation while the larger volume of air in the pipe is compressed to operating pressure. The installation of this type of brake requires some exhaust work, cutting and removing a section of the existing exhaust pipe and inserting the brake in that area with the supplied flanges, clamps and connectors. Because it is installed under the truck, this type is more routinely exposed to the elements and, as such, will require more attention than the under-the-hood turbo mounted brake. Maintenance on any brake is minimal, with some manufacturers supplying a lubricant for the main pivot bearing while others are completely maintenance-free other than to check the hoses and fittings for wear or leaks.

Now that you have the mechanical part of the brake installed you have to decide which method of activation you are able to use. Most of the brakes, regardless of mounting location, use either a "push" using a positive-air cylinder, or a "pull" using vacuum

cylinder to activate the butterfly valve. In the default-off mode they have a very strong spring to return the valve to the open position and keep it there until called upon to activate and close. They use either a small air pressure cylinder or a large 2"-3" vacuum cylinder to activate the valve. On the trucks with a factory vacuum pump the brake systems use this available vacuum supply to apply the force needed to close and hold the valve, but not all trucks have a vacuum pump nowadays. In this case you will need positive air pressure to power the brake and these brake systems often include a small air compressor and tank that will need to be mounted somewhere, usually under the hood, to supply the proper regulated pressure. One exception to the air activation is U.S. Gear, which makes the D-celerator brake and as far as I know it is the only one that offers an electrically operated brake. Some manufacturers, such as Banks, supply as part of their kits, a small belt-driven vacuum pump for the '04.5-'07 trucks instead of an air compressor. Both air-based methods use an electrically-operated solenoid valve to activate the system and apply air pressure/vacuum as called for by the next important element of the system, the controller.

You could use a simple switch to activate the solenoid that controls the positive or negative airflow to turn the brake valve on and off, using it as needed whenever you chose to do so, but there is a problem with this simple method. If the brake valve were to be closed when you applied the throttle, the increase in exhaust pressure with no place to go could have bad results. It is for this reason that exhaust brakes are supplied with an electronic controller that will sense fueling and open the valve whenever you touch the throttle pedal. They are typically wired into the accelerator pedal position sensor (APPS), or throttle position sensor (TPS), or tapped into the PCM (Powertrain Control Module) or ECM (Engine Control Module) to allow you to leave the brake switched on without being operational until your foot is off of the throttle. Some of the brake manufacturers have a connector that plugs directly into the OBDII port and reads engine/transmission function from that source. On older manual trucks without modern electronics, an on-off switch is installed, usually on the fuel pedal arm or out at the injection pump, that does the same thing. These sensors/switches also tell the brake when to engage by sensing when your foot is off the throttle. Now you have a simple switch that is able to turn the system on or off without worry. This brings us to the next control issue, the differences between how the brakes work on a manual or an automatic transmission.

I sometimes envy those of you with a manual transmission and the ease and effectiveness with which you are able to use the brakes on your trucks. You can use the brake in any gear you choose to, right down to first if needed. You can decide when to turn it on or off, at any speed or RPM and it obeys. Because the connection between the engine and the rear wheels is a direct couple, whenever the clutch is engaged, there is nothing to control except the throttle pedal/fueling sensor to make certain that the brake disengages when the throttle pedal is contacted. And because *you* control when the brake is on, it can be turned on manually to speed the warming of a cold engine, although some auto controllers do offer a cold warm-up feature also. You can also use an exhaust brake on virtually any year-model manual truck, something that is not true of an automatic.



**Those with a manual transmission can use this gear shift with a switch at the top to turn on/off the exhaust brake. Trick, eh?**

With us automatic guys it is entirely another story. Merely activating the brake when letting off the throttle would close the butterfly valve and restrict exhaust flow, but without a solid connection between the now-retarded engine and the rest of the drivetrain, driven by the energy of the moving truck, there is only a minimal braking effect. Our torque converter (TC) clutches are designed to release upon deceleration, causing the torque converter to just spin and create heat instead of connecting the vehicle's momentum to the now-restricted engine. The torque converter clutch needs to be locked in order to make the brake work effectively. This means that older automatic-equipped trucks (vintage '89-'93) with non-locking converters won't be able to use a brake on their trucks.

So along with the fueling sensor there has to be some way of locking up the torque converter (TC) clutch when the throttle is closed and the brake is activated by the controller. Most brake manufacturers offer a separate, additional controller for use with automatic trucks that monitors the PCM or the ECM to sense vehicle speed, fueling, torque converter clutch status, and forward gear status. If yours is a '94-'02 truck and you are interested in adding an exhaust brake to your vehicle, you're going to have to do some research because the electrical interface to keep the TC clutch locked up is not as refined as it is with Third Generation trucks. A suggested starting place, Issue 64, page 76. Pull out that back issue and you'll see that we owe a debt of gratitude to early Turbo Diesel pioneers and writers.

With 2003 (Third Generation) and newer models this additional lockup controller is sometimes combined in the same module with the basic controller. The 2006 trucks use the ECM itself to control the brake functions. These controllers will allow the brake to activate and the TC clutch to lock, but only when meeting certain pre-set requirements that are designed into the software. They will only allow the brake to engage above a certain speed or RPM, and in certain gears, and when slowing down will release the brake as well as the TC clutch, when a pre-determined vehicle speed, or RPM, or both, is reached, taking some of the control away from the driver and giving it to the controller. This is necessary because you would not want the TC clutch to remain locked when you come to a stop, this being similar to not disengaging the clutch when slowing.

Each manufacturer sets this lower limit as they see fit. Because transmission fluid line pressure is reduced when coasting, some brake manufacturers also include an air or vacuum cylinder and the associated hardware to increase the line pressure to make sure the torque converter clutch does not slip under the added stress of braking.

While on the subject of automatic transmissions, let's make things more complicated. Did you realize that Dodge does not officially support the use of an exhaust brake on any automatic truck before the model year 2006 due to concerns about transmission durability? Starting in 2006 they offered a brake installed and warranted from the dealer on these vehicles. There are, however, a lot of owners of the "unapproved" automatic-equipped trucks out there, myself included, that have been using a brake on our auto trucks for many years without any problems from such use. Most of these trucks are out of warranty anyway and the added safety of having an exhaust brake while towing far outweighs Dodge's concerns.

But, you may ask, isn't the automatic transmission from '03.5 to '07 the same unit, a 48RE? Yes, but the saga of exhaust brake approval by Dodge took until model year 2006. The final chapter to the story is found in TDR Issue 55, page 15.

Another issue with an automatic transmission concerns the matter of which forward gear you are able to use the brake in. In a stock truck (up to 2007 with the 48RE) the valve body setup only allows torque converter clutch lockup in overdrive and direct, or third gear. This means that the brake is most effective at higher vehicle speeds where the engine RPM is increased. Upon slowing, once you reach that pre-set minimum speed or RPM you will feel the brake release and you are back to the pedal to further slow and stop. When my 47RE transmission was stock I was only able to use the brake in these two higher gears; but with a modified valve body I can now switch off overdrive and manually downshift into second gear, and the brake remains activated and the TC clutch locked, raising RPM and allowing the brake to be engaged down to lower speeds. Some aftermarket transmissions/valve bodies will also allow a first-gear lockup. This results in the brake being far more usable at lower speeds by keeping the engine RPM up.

In 2004.5 you still have the overdrive-off option and at this time the tow/haul feature was added to trucks with the 48RE auto which, when activated, changes shift points and TC clutch lockup characteristics that will change the way the brake works when decelerating. The 2005 model years had tow/haul but no overdrive-off feature and then in 2006 and newer trucks with both tow/haul and OD-off were provided and still further change the way an exhaust brake will function depending on how these controls are used by the driver. As you can see, if you have an automatic transmission in your truck, there are several things that change the way a brake works; but these are, for the most part minor operational issues.

So far the basic functions of an aftermarket exhaust brake as I have been describing them apply to any year truck, but in 2007.5 with the 6.7-liter engine, Dodge has eliminated the need for an aftermarket brake by supplying the engine with a VGT, or variable-geometry turbocharger. These turbochargers are able to internally vary the size and shape of the exhaust turbine housing in order

to offer a wider and more effective turbo mapping range, offering more usable boost and better turbo spool up throughout all engine speeds. By way of a sliding nozzle ring within the exhaust turbine housing, the exhaust path can be varied and closed off to allow this turbo to become a very effective exhaust brake as well as a turbocharger. The great thing about this is that it is completely integrated into the truck's electronic controls and transmission systems for smooth and reliable operation. When used with the newer 68RE six-speed auto transmissions, with the tow/haul, gear selection, and OD-off controls, these newer trucks offer a brake that is much more tunable than the previous add-on models. Your Issue 70 magazine has the complete story on the VGT turbo. See pages 46-50.

### Which Brake to Choose?

All the manufacturers will assure you that they have the best brake with the least amount of exhaust restriction when open and the strongest braking force when applied. They all claim the shortest stopping distances and offer proof in the form of colorful charts and graphs in their advertising to show how they are superior to the others out there in their quest for your business. I have never heard anyone really complain about their specific-brand braking performance; they all do the job well, and although I'm sure there are some differences, it can also be said that any brake is better than no brake. If you are going to seriously consider adding this very useful option to your truck, do your research and talk to other owners that drive the same truck that you have and then decide which one is best for you. There are certain model-specific restrictions on these brakes and each brand operates with slight variations with an automatic, so I would suggest that you do your homework to see what would work best for your particular application. Find the best option and get it installed, you won't regret this addition to your truck. Because while Mo-mentum is all well and good, sometimes you need a little Less-mentum, and an exhaust brake will give you just that.

### References Please...

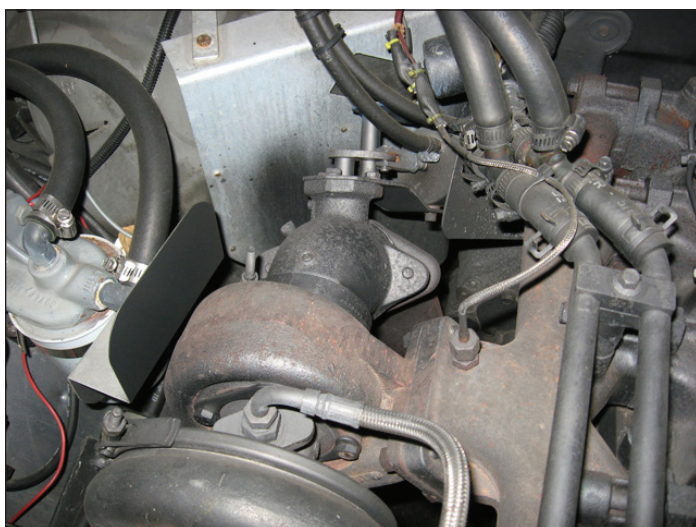
To simplify your research you need to start by looking at the TDR index that is (was) a yearly project by Bob and Jeannette Vallier. Key magazines you'll need: Issue 65, 61, 57, 53, 49, 45, etc. Turn to the column "TDResource" and the title "Annual TDR Index." From there look up "Exhaust Brake" and you can read about the TDR writers' experiences with the installation of brakes on both manual and automatic transmission trucks. Read about the different exhaust brake designs from BD, Banks, Cummins/Jacobs and Pacbrake. Read about non-warranty approved usage of brakes with automatic transmissions. Read about the different ways to activate the brake with an automatic transmission. Read about modifications to the automatic to keep the transmission locked-up. All of the read-about's will make the decision easier and help save your hard-earned money.

**David Magnoli**



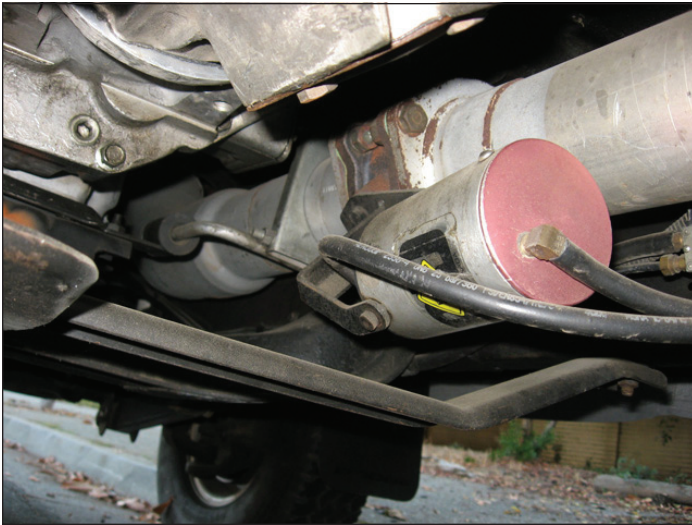
The Banks Brake on my truck is typical of turbo-mount brakes, replacing the stock transition elbow that connects the turbocharger to the downpipe. Being under the hood makes them less exposed to the elements than the inline models and also makes installation a simpler, bolt-on procedure.

Mounting close to the engine also keeps the run of hoses to a minimum with less chance of damage. If you have twins or a non-stock single turbo though, this type is not an option.



The top picture is of the Cummins/Jacobs version of a turbo-mount brake installed on a 2002 truck. The vacuum cylinder is smaller and is positioned down lower next to the firewall than the Banks version.

The lower picture shows a PacBrake installed on a First Generation, manual transmission equipped truck and is very similar to the Jacobs in the positioning of the air cylinder.



**You can see that the inline, under-truck mounted exhaust brakes install in the exhaust pipe instead of directly on the turbo. They are a little more work to install because the existing exhaust pipe must be cut to allow the brake housing to be inserted. They are more exposed to the weather in this location. This one has the flanges nicely welded to the 4" pipe for a leak-free installation.**

## **DON'T CALL IT A JAKE BRAKE**

Although "Jake brake" properly refers to the Jacobs brand of engine brakes, the term has become a genericized trademark and is often used to refer to engine brakes or compression release engine brakes in general, especially on large vehicles or heavy equipment. As we learned earlier, ours is not an engine or compression brake, but rather an exhaust brake.

On larger diesel engines with an engine or compression brake (not a potato-up-the-exhaust, exhaust brake like ours), an additional exhaust valve opens to bleed off this compression at the right moment so that its force is not returned to the engine. This system takes advantage of the piston working against the air in the cylinder to slow the rotation. Such a system is operated by a lobe on the camshaft and is designed as part of the cylinder head. Compression brake activation by the big-rig driver allows compressed air to escape from the cylinder prior to the injection of fuel and the power stroke is canceled. If you've ever driven beside a big rig when they activate their compression or "Jake brake" you know what the power stroke cancellation sounds like. Blahhhhhhhhhh, blahhh, blah, blah, blah, rap, rap.

This compression-style brake was originally designed by Mr. Cummins. Mr. Cummins retired from Cummins Engine Company in 1957. However, he stayed active in the diesel business. In his book, "My Days with the Diesel" Mr. Cummins tells us the story about the development of the compression brake. "In addition to getting involved in a variety of new activities, including cattle ranching, I have proceeded with some important developmental work in the diesel field. Among these engineering advancements is a relatively simple accessory which converts a diesel engine into a highly efficient air compressor whenever vehicle retardation is needed. This 'engine brake' will hold a thirty-five ton truck under complete control (limiting speed to 19 mph) going downhill on a 10 per cent grade without use of the service brakes. Manufactured (under license) by the Clessie L. Cummins Division of the Jacobs Manufacturing Company (a subsidiary of the Chicago Pneumatic Tool Corporation), my diesel engine retarder already has been installed on thousands of trucks, eliminating for drivers the hazards of runaways and saving big money for operators in the form of reduced maintenance of the vehicles' conventional brakes."

And, now, you know the complete story behind the Jacobs brake (aka, engine or compression brake) and our little exhaust or potato brake.

# Exhaust Brake Valve Springs/ Valve Spring Adjustment

ISSUE 54, ISSUE 30, ISSUE 29

## **FITTING AN EXHAUST BRAKE TO A SECOND- GENERATION CUMMINS-DODGE TURBO DIESEL TRUCK**

by Bob Vallier

### **Both halves of a two-half story**

This spring I bought my first travel trailer, something I'd put off doing for ten years. And I decided to convert my Second Generation Turbo Diesel from a general roustabout into a dedicated trailer hauler.

This newly dedicated hauler is my senior Turbo Diesel truck—a '94, four-wheel drive, long bed, 12-valve—packing 115,000 on the odometer, in top running order, thanks to the tutelage of the TDR and a good mechanic in the neighborhood. "Just broken in," I like to say. My new travel trailer is a 19-foot Fleetwood Pioneer rated at a GVWR of 6000 pounds, 500 at the hitch. I knew that my truck was more than a match for the load, so at first I wasn't convinced I'd need to make any modifications to the truck. However, after testing braking performance on a 3,000-mile, trailer-pulling shakedown in the intermountain West last spring, I decided to follow the unanimous advice of TDR writers and install an exhaust brake.

I was soon to find that installing the brake was "only half the story" (which just happens to be the theme of this issue of the TDR). But, first, the first half.

The truth is I had managed to negotiate the grades on my test run with no apparent braking problems, relying on the trailer's electric brakes and the truck's service brakes alone. I like to say that I could drive half a day pulling the trailer in the hills and use the brakes less often than in ten miles across Tucson. But I knew from years of reading the TDR that I could conserve my truck's service brakes and probably also save my trailer's electric brakes, by adding an engine-exhaust compression brake. Finally, I recalled advice from Jim Anderson on one of his visits to southern Arizona when he revealed that he used his exhaust brake all the time, even when he wasn't towing. I could see that the idea had merit.

I knew I was going to need some help. My field of expertise (and everybody has one) is linguistics and semantics—that is, my day job has been fiddling with *how* things are written, not so much *what* is written about. You might say that I play the language game. I also play with trucks. But in this latter field I'm a rank amateur. While I like to think I drive off-road with the best of them, when it comes to mechanical work on my rig, I am glad to get help on any job more technical than changing wiper blades.

I did the obligatory research on brands of exhaust brakes and learned what I expected, that there are several very good makes. On the advice of savvy trailer-hauling desert rats hereabouts, I decided on the Pacbrake.



**The Pacbrake kit.**

I was told by a local Dodge dealership in Tucson that there was no Pacbrake available for a '94, 12-valve Turbo Diesel. The men at Pacbrake had a good laugh and sold me a unit off the shelf specifically made for the 12-valve Cummins system (part number C14000, \$820). I got the package via overnight delivery.

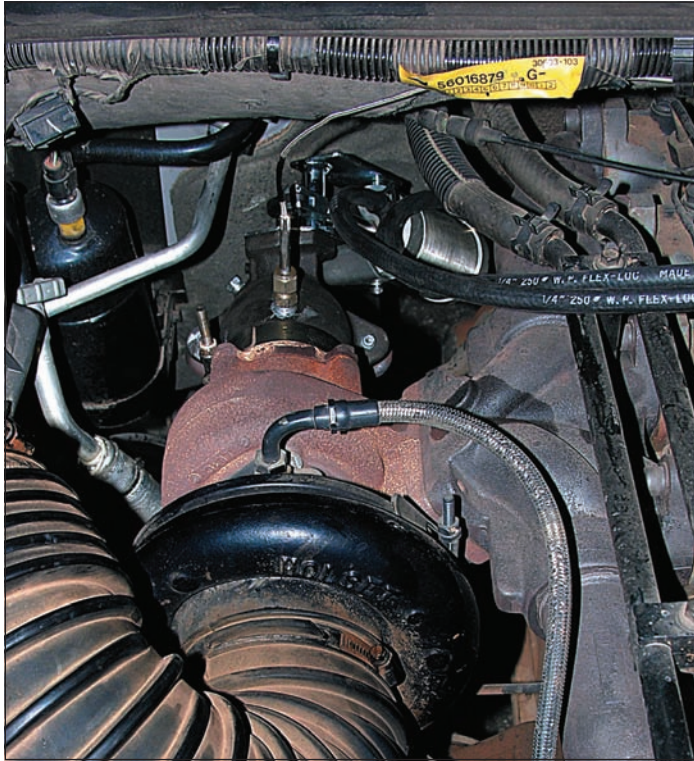
For installation, I decided to bypass the Tucson Dodge dealership (remember, they are the guys who said there was no such animal as a Pacbrake for my 12-valve rig) and instead work with a local garage here in the desert village of Oracle, 35 miles from the big city of Tucson.

For the 11 years since retiring from teaching at the University of Tennessee, I have found that the local garage just down the street, Troy Letwak's Oracle Auto Repair and Parts, consistently gives me the kind of careful attention to detail that a truck owner doesn't always get in the big-city dealerships. Troy is particularly blessed in his chief technician, a mechanic of vast experience and skill—a gentleman by the name of Peter Van Keuren—who has kept my three trucks running and solved every mechanical problem I could throw at him.

Anyway, Peter followed the printed instructions provided by Pacbrake, right down the line, and finished the job in an hour and a half. Neat as a pin. A shadetree mechanic should have no misgivings about doing this job. Installing the brake valve between the Turbocharger and the exhaust pipe is straightforward, and the wiring is basic. Pacbrake's instructions are clear as crystal. I observed the whole process and, in spite of my being mechanically illiterate, I would do the job myself on another installation of a Pacbrake if the need arose and Peter were not available.

But, as I've been hinting, installing the brake itself is "only half the story" —and not the toughest part either.

The toughest part would be changing the exhaust valve springs. You ask, "Why change the springs? This is starting to sound too complicated." Let's examine the "why."



The Pacbrake was installed in 90 minutes. However, the install was only half the story. Next it is time to change exhaust valve springs.

The '89-'98, 12-valve engines have exhaust valve springs that are capable of closing the exhaust valve at up to 35 psi of back pressure. If you put an exhaust brake on the truck and the closed exhaust brake creates back pressure of over 35 psi, the pressure can hold the exhaust valve open. Valves that are open at the wrong time will collide with pistons and the resulting bent valve is a **really** bad thing.

To keep the exhaust brake from making too much back pressure, most of the exhaust brake manufacturers make allowances for customers that want to continue using the stock 35 psi springs. Some leave a hole in the exhaust brake's flapper door; some open the flapper door when 35 psi is generated. Others give you no choice and insist that you install the 60 psi valve springs.

At the outset of the project I had decided to hold off on changing the exhaust valve springs. I wanted to test performance with the stock valve springs (35 psi design) first. After all, why incur the expense of extra shop time if I were satisfied with performance without the 60 psi springs?

A quick road test answered that question: without the 60 psi heavy-duty springs, I wasn't going to get the extra braking I wanted. And

I was spooked by the frequent warnings on the web that said that I risked floating valves and consequent engine damage unless I upgraded to the 60 psi springs. To clinch my decision, Pacbrake had told me it was standard procedure to change the springs.

What I faced now was a classic case of "*only half the story*." Putting in the Pacbrake had been a snap. But getting the valve springs swapped-out was an entirely different story. I knew that I didn't have a clue about how to do it. Years of reading the TDR had taught me that I'd better go back and do a little bit more research if I were to be a responsible truck owner.

I studied back issues of the TDR. I learned what I could on the web. I nosed around service facilities in the region to get an idea of what a valve-spring replacement job would involve and to get estimates on shop time and cost. Cummins in Phoenix would do the job but declined to give me an estimate. A local Ford dealer said they'd never done a valve spring replacement on a Cummins engine, didn't have the necessary tools and would rather not take it on. An independent mid-size engine shop in Tucson that works on Cummins engines regularly, advised me to go to the Dodge dealership. The Dodge dealership estimated eight hours; and at \$106/hour that was farther than I could see with the naked eye.

I checked with the service department of the Camping World shop at Beaudry's in Tucson, reputed to be the largest RV sales organization in America; they said they were happy to install the Pacbrake itself, but they had no idea who could or would swap-out the valve springs. That was beyond them. I scratched my head. It seemed easy to find a garage that would install the brake, but tough to find the technician to do the recommended valve spring swap. Was everybody leaving the job half done?

This curious discrepancy does not present a problem in post '98.5 and newer engines as these engines come with two exhaust valves per cylinder that will close in a 60 psi environment. And it is a safe bet that most folks with 12-valve engines have already installed an exhaust brake long ago if they were ever going to do it. But for me, a Johnny-come-lately convert to the exhaust brake, it presented an immediate challenge, one possibly shared by other owners of Second Generation pickups with latter-day plans to install an engine exhaust brake.

My research effort was further confused when I realized that there are two different opinions on the right way to do the job and each technician I talked to was a strong adherent to one opinion or the other. One opinion followed the time-honored shadetree method described in TDR write-ups over the years, namely to elevate each piston manually to Top Dead Center, thereby holding the valves in their closed position. This method is best described in TDR Issues 17, pages 68-70; and 36, pages 124-126. This method is revisited in the side-bar article "My Way." The other opinion prescribes using an air-hold tool to pump compressed air into the cylinders and thereby hold the valves closed regardless of piston position. (For crying out loud! Even "the other half of the story" has two sides.)

I was just about to pack up my truck and head out to Carson Dodge and let John Holmes do the job, except I knew he'd sell me a new truck, which wasn't in my plans.

I returned to Troy's establishment and huddled with Peter Van Keuren over the results of my research. He is a monkey-wrench scholar and so he took several of my TDR back issues home overnight and studied everything printed over the years about changing engine valve springs. He conceded the practicality of the "top dead center" strategy, particularly where compressed air is not available. However he opted for the air-hold method. His argument was simple: "With air there is less likelihood of misadventure. Shop air is a valuable tool, and we should use it when we can."

I wasn't surprised. I had found that every regular shop I talked to insisted that they would not do the job any other way than with the air-hold tool. This group included the Dodge dealership with the highfalutin' price quote, but also the shops that declined to do the job because they didn't have the necessary tools, or for whatever other reason.

Troy's shop didn't have an air-hold tool in its toolbox either, so we set to work on the internet and found the very thing, made by Mityvac, part number MVA5602, listing at \$27.50, available from "Tool Source" (888-220-8350; [www.toolsource.com](http://www.toolsource.com)) and other distributor/dealers.

Peter's first step was to modify the Mityvac into an air-hold tool. He cut off the quick-connect end of the adapter, drilled the hole to 7/16 inch, tapped the hole to quarter-inch pipe thread, and installed an air bib. (See the before and after photos of the Mityvac.



Before beginning, I want to tell you that this is a job requiring knowledge of the parts of the Cummins engine and their working interrelation and some practiced experience in actually working on the engine. Replacing the valve springs is not a complicated process. Peter handled it with élan and it was simple the way he did it. But I would not myself undertake it, even now with the benefit of having observed the job. However, I have many truck buddies who wouldn't blink twice at it.

Peter gave the whole job a total of four hours. His procedure replaces the valve springs **one cylinder at a time**, using the Mityvac adaptor as an air-hold tool to hold the valves closed, the one critical provision in this process.

The procedure begins with removal of the valve covers. Note that there are two bolts holding the rocker arm tower at each cylinder, a 13mm positioning bolt (torque value 18 lb-ft) and a large 18mm cylinder-head bolt.

Among TDR writers there was not an agreement on the instructions for reinstallation of the head bolt(s). Since the writers did not agree, I called several sources within the Cummins, Inc. organization. Still no agreement. Time to do the obvious—consult the DaimlerChrysler factory service manual. Under the section "Rocker Lever and Push Rod Removal" you will find the following:

- Use clean engine oil to lubricate the cylinder head bolt threads and under the bolt heads.
- Tighten the bolts to 66 ft-lbs torque.
- Then tighten the bolt to 89 ft-lbs torque.
- Finally, tighten the bolt an additional 90°.

This is the procedure to be used when you retighten the 18mm cylinder head bolt.

Order of disassembly is as follows:

- As a safety precaution, drain the engine coolant to a level below that of the cylinder head deck.
- Remove a single cylinder valve cover. It is not necessary to remove rocker arms.
- Remove the bolts for the rocker pedestal (13mm positioning bolt and 18mm head bolt).
- Remove the appropriate fuel injector.

- Thread the air-hold tool (i.e., the MVA5602 injector adaptor) into the vacated fuel injector opening. Note that it is through this opening that compressed air is introduced into the cylinder.
- Take a socket, approximately the size of the spring retainer; and, once the air is applied, tap the socket to break the taper on the collets.
- Install spring compressor such as the KD2 #3271 and compress the spring; with a pocket magnet remove the collets.
- Remove the compressed stock spring.
- Then, reversing the sequence, one at a time compress the new, heavy-duty spring with the retainer on the spring, and drop it back on the valve stem.
- Don't forget to screw the spring into the compressor as far as possible before compressing the spring.
- Snug two collets to the stem.
- Release the compression tool.
- With a brass punch, tap the valve stem to seat the collets against the retainer.
- Reinstall rocker arm tower (13mm positioning bolt, 18mm head bolt).
- Double check valve/rocker arm clearance (.020").
- Reinstall valve cover.
- Proceed to the next successive valve spring.
- At re-assembly, re-adjusting the valves should not be necessary, that is, if nothing has changed in the relative positions of rocker arms and push rods.
- I suggest you have four extra collets on hand, Cummins part number 3900250 (84 cents each).

- Other parts include the KD tool spring compressor, available at NAPA, KD2 #3271; six valve cover gasket sets (part number 3930906, \$4, each of which includes the cover-bolt O-rings). The set of heavy-duty springs is from Pacbrake, part number 14010, \$58. The MVA5602 air-hold tool we used on this job is mine now, and since I don't expect to be using this little gizmo again anytime soon, the first member who requests it can have it for shipping costs, which I imagine will be less than ten dollars. Drop me an email: [vall@theriver.com](mailto:vall@theriver.com).

Finally, there is an interesting footnote to my amateur's search for "the" method to swap out engine valve springs. After Peter had performed his act, I took my 12-valve truck for some other work at a performance shop I'd overlooked in my earlier search:—Desert Diesel, a fully equipped professional performance shop in Tucson, owned and operated by Frank Pfeiffer for more than twenty years, who routinely upgrades Dodge Turbo Diesels. (*Desert Diesel*, 2395 N. Fairview Drive, Tucson 85705; phone: 520 792-0132.) In five minutes of conversation Frank solved my quandary over the "right" way to swap out valve springs. He explained that in the Cummins engine the piston deck is flush with the head deck and therefore there is not the potential danger from falling valves present in other makes of engine. The scales dropped from my eyes: the picture came into focus. I showed him my copy of the TDR articles on swapping engine valve springs, and he agreed that his shop method was essentially the same. There is more than one way to skin a cat. Or to cite the original version from Charles Kingsley's *Westward Ho!* In 1855, "There are more ways of killing a cat than choking it with cream."

In retrospect I can say that if I'd had the mechanical experience of many practiced TDR members, I would have done the shadetree operation myself, following the "top dead center" procedure. However, given my limited skills, what I did worked for me. And in this undertaking I learned a lot that I wouldn't have picked up any other way. (I'm a lifetime student.) In spite of some wasted motion, in the end we finally got the two halves of the story to come together. Jeannete, *Meine Frau*, says that with our new Pacbrake—and the heavy-duty valve springs—she's confident she could tow a freight car on the infamous grade out of Searchlight, Nevada. We just happen to be headed that way. At last, this trailer-pullin' 12-year-old Turbo Diesel is ready to roll!

**Bob Vallier**  
TDR Writer

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**MY WAY**  
by Robert Patton

As the researcher and writer of the Top Dead Center method I could not let the opportunity pass to revisit this installation technique. Besides, I'm the editor too! Additionally, this information gives you the complete understanding of "my half of the story," and it gives you the full text of this alternative installation method.

If you're confident you can do a valve lash adjustment, you have the basics to do an exhaust valve spring change. To do a valve lash adjustment you've got to start by finding the top dead center of the number one and six cylinders. To do the necessary work, let's review a process called "valve overlap," as we're going to use valve overlap exclusively in the exhaust valve replacement procedure.

### Why Top Dead Center

When changing the exhaust valve springs you have to prevent the exhaust valve from dropping into the cylinder as the exhaust valve collets are removed. I've seen many techniques for ensuring the valve does not drop into the cylinder. You can remove the injector and, with a modified injector shell/air tool, fill the cylinder with air pressure. You can remove the injector and use a flashlight to watch for the piston to reach top dead center. Or, you can follow the easy technique described below.

The simplest way to prevent the exhaust valve from dropping is to have the piston at top dead center. Now, when you release the exhaust valve collets and remove the valve spring, the valve has no place to go! We are going to use the valve-overlap method to find piston top dead center for the exhaust valves we are replacing. A quick review of valve-overlap is in order.

Take a minute to think about a six cylinder engine and the operation of the pistons to top dead center. Pistons in cylinders one and six are "companions"; they're both going up and down at the same time. Imagine that piston one is on the exhaust/intake stroke, while six is on the compression/power stroke and vice-versa. Knowing that one and six are companions, I want you to remove the valve cover to cylinder one (the cylinder closest to the radiator) and cylinder six (firewall). Using your preferred method rotate the engine to watch the valve action of cylinder one.

Now, think about the movement of the valve train and the four stroke cycle. Starting with the intake of air (a)...hold it. Back up just a bit. As the piston is traveling to the top, it is pushing exhaust gasses out of an open exhaust valve (rocker arm down). As the cylinder one piston reaches the top of the stroke, the intake valve starts to open from its horizontal position (a). You've found the piston at the top of its exhaust/intake stroke. Rock the engine counter clockwise to confirm the overlap condition. Pistons one and six are at the top of their respective strokes (one is on exhaust/intake stroke; six is at the top of compression and is "firing" to make power). Piston six is at the official "top dead center" location. Skeptical? Check to see that the cylinder six valve rocker arms move freely. I'm certain they do. It is now time to replace the number one cylinder exhaust valve spring. We will replace the number six cylinder exhaust valve spring next.

Wait a minute...We're watching the rocker arms "act" on the number one cylinder. Shouldn't we change only number six, as there is no rocker arm tension on number six?

Not necessarily. While there is rocker arm tension on the number one exhaust/intake valve, this is not a concern if you use the rocker tower method of exhaust valve spring removal/replacement that is described by Bob and Pete.

I've got you started on exhaust valve removal/replacement on number one because this is the easiest cylinder to access. Realizing that it is necessary to remove six of the 18mm cylinder head bolts (one at a time), it is good practice to drain the engine coolant to a level below that of the cylinder head deck.

Let's get started. Loosen the 13mm bolt that positions the rocker arm tower.

Before loosening the rocker arm pedestal/18mm cylinder head bolt, mark its position using white paint. Mark the bolt head and the pedestal. This will give you a reference point for the correct retorque of the 18mm cylinder head bolt that Bob presented from the DaimlerChrysler factory service manual. Again, remove only *one* pedestal at a time. Do *not* remove all six at once. Remove the 18mm cylinder head bolt and rocker arm pedestal and proceed to the replacement of the exhaust valve springs as Bob and Pete described.

**Robert Patton**

**TDR Editor**

## VALVE ADJUSTMENT PROCEDURE – 24-VALVE

So, you're jealous of your 12-valve counterparts due because they should adhere to a 24,000-mile valve adjustment schedule. Do you long for that type of close relationship with your engine? Perhaps you thought the valves were "self adjusting" (don't laugh, I read it on the web site). Well, there is no stopping you from taking that one-piece valve cover off your beloved 24-valve engine and checking your valve lash settings. What? You don't know how?

While the TOR is a good source of information, the *best* source is a Daimler/Chrysler, Dodge 2500/3500 Service Manual. If you don't already have this book, I would strongly suggest you purchase the manual. An order form is conveniently located in the back of your vehicle's Owner's Manual.

### Tools Needed

|                      |                   |
|----------------------|-------------------|
| Valve cover removal: | Valve adjustment: |
| 15 mm socket/drive   | 14 mm wrench      |
| 15 mm wrench         | 5 mm hex head     |
|                      | Feeler gauge      |

Engine barring:

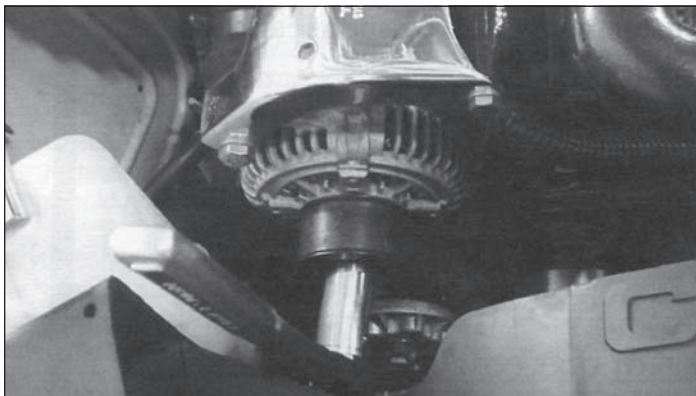
- 22 mm socket/drive (preferred alternator method)
- 15 mm socket/drive (crankshaft dampner bolt method)
- Service tool 7471 B, engine barring tool/drive

Crankcase breather removal:

- Strong hands/improvise (I won't discuss my barbaric hammer-to-the-left crack-the-breather-assembly method of removal)

Let's combine some of the tips from the 12-valve adjustment article in Issue 29 with the factory Service Manual to present the how-to for the 24-valve applications.

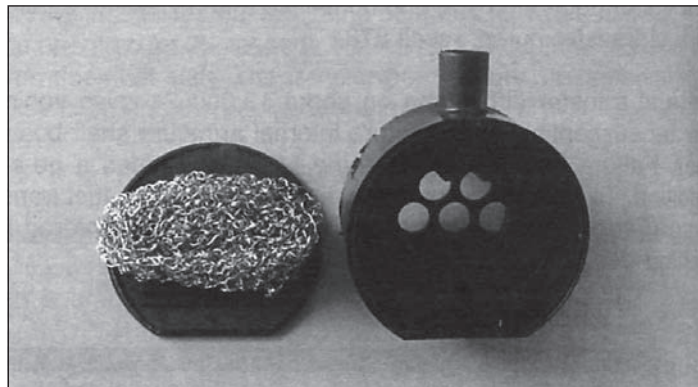
First step: find engine top dead center (TDC). The manual suggests using an engine barring tool to find TDC. I would suggest the simplistic 22mm alternator nut technique or the 15mm crankshaft dampner bolt technique (discussed in detail - Issue 29, page 44). Regardless of your method to spin the engine, TDC is easy to locate on the 24-valve engines. No more awkward timing pin to try and push into place. One can even dispense with the voo-doo valve overlap magic that was the focus of our Issue 29, page 44 and 45, 12-valve article.



The editor uses the 22 mm alternator nut technique to bar-over the engine.

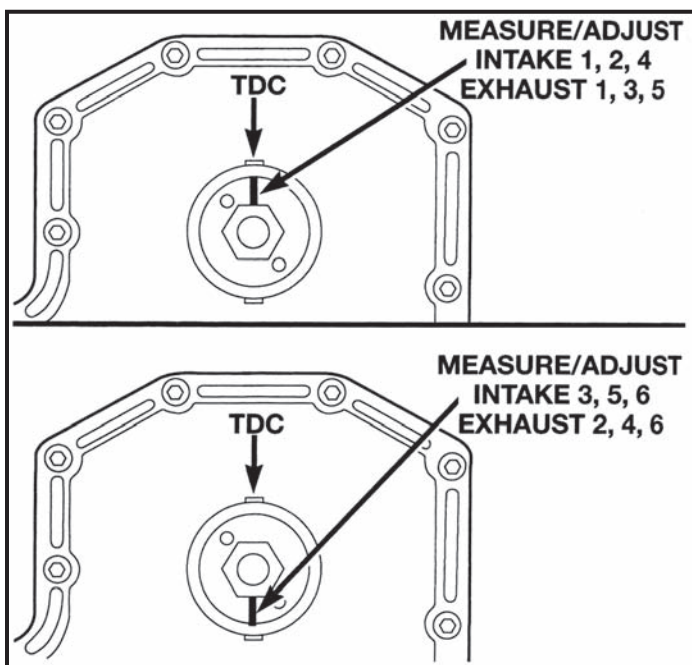
With the 24-valve engine there is a timing mark at 12 o'clock stamped onto the stamped-steel gear cover. There is also a mark on the fuel pump gear. Thus, we need to remove the fuel pump gear access cover to do the alignment of the reference marks.

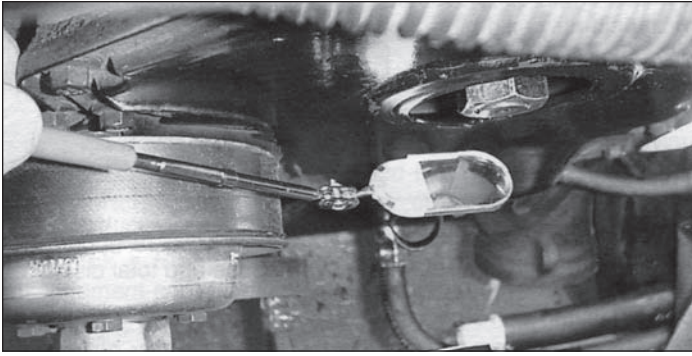
While the service manual says, "remove the fuel pump access cover," in Dodge applications of the 24-valve engine the access cover is replaced with a crankcase breather assembly. Contradiction: instructions in the manual show a counter-clockwise removal of the access cover. The Cummins parts book shows the crankcase breather assembly as a press-on option. It is not pressed-on (this is the voice of experience speaking).



Ever wonder what the inside of your crankcase breather assembly looks like? Follow the instructions in the article and you will not have to see inside the cover/repair the cover like the editor did.

Remove the crankcase breather tube from the assembly. Then, turn counter-clockwise to remove the assembly from the gear cover. Now you have access to see the fuel pump gear timing mark (you'll need a mirror for this). Align the timing mark at 6 o'clock or 12 o'clock. For kicks, remove the one-piece valve cover prior to barring the engine over and watch for valve overlap (Issue 29, page 45) on the respective cylinder one, 6 o'clock; cylinder six, 12 o'clock.





**Using a mirror to see the timing mark.**

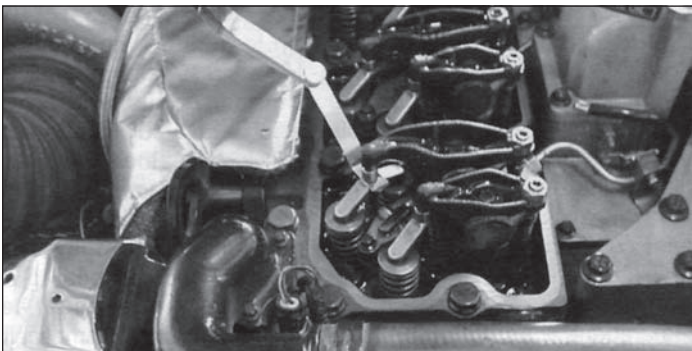
Second step: valve adjustment. With the timing mark at 12 o'clock adjust the valves for intake cylinders one, two and four; exhaust for cylinders one, three and five.

With the timing mark at 6 o'clock adjust the intake valves at cylinders three, five, and six; exhaust for cylinders two, four, and six.

The valve lash limits are as follows:

- Intake – minimum .006 in (.152mm),  
maximum .015 in (.381 mm)  
reset valve .010 in (.254 mm)
- Exhaust – minimum .015 in (.381mm),  
maximum .030 in (.762mm)  
reset valve .020 in (.508 mm)

If the valve lash needs adjustment use a 14 mm wrench to loosen the rocker arm and use a 5 mm hex head to make the adjustment as necessary.



**Setting the valve lash of the exhaust  
(exhaust are the outermost valves) on cylinder one.**

Reassemble the crankcase breather/access cover. Reassemble the valve cover to the engine. The valve cover gasket is likely reusable as the design criteria allows for multiple reuse. If a new gasket is necessary, the latest Cummins part number is 3935878 at \$38.07. Torque the 15 mm valve cover bolts to 18 ft-lbs.

Special notes to the 12-valve owners: did you note the adjustment "window" for valve lash settings (.009 inches intake, .015 inches exhaust)? If our 12-valve engines had such a wide window, I think you could safely call the 12-valve overhead a low maintenance design too! As an aside, the acceptable, unpublished, window used at the factory for the 12-valve engines was .004 inches (+/- .002).

## VALVE ADJUSTMENT QUESTION – 12-VALVE

Is the 24,000 mile valve adjustment necessary on my '98 12-valve Turbo Diesel? My Dodge dealer says it is a waste of money.

Robert Gordon

*I would agree, but you can't say "for sure" with confidence, until you've done the valve adjustment. Perhaps then move your schedule to every 48K. We outlined the how-to of valve adjustment way back in Issue 12, pages 66-68. I went back to Issue 12 and critiqued the article. Below is the refresher/result.*

**Much of the following information comes from the Cummins B series Operation and Maintenance manual. As noted in Issue 28, page 108, these, and other Cummins reference books, are now available on-line. Good material, good service and an easy- to-use site are attributes of [www.powerstore.cummins.com](http://www.powerstore.cummins.com). Without further delay, the following is the step-by-step valve adjustment technique.**

### Valve Adjustment

Tools needed:

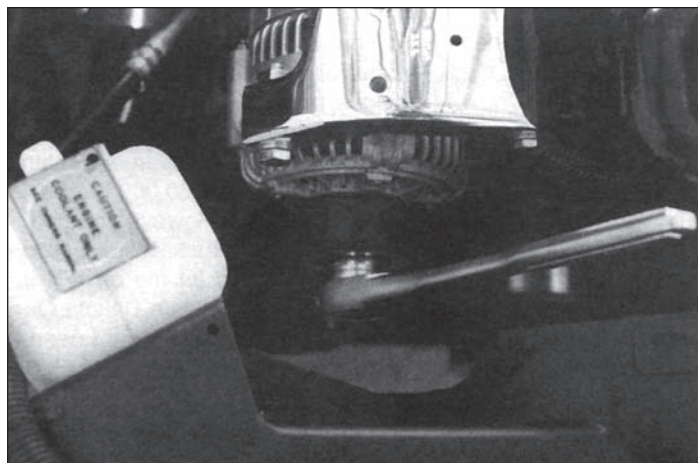
- 15mm wrench/socket
- 14mm wrench/socket
- Flat blade screwdriver
- Feeler gauge
- \*1/2 inch drive with extensions
- \*Cummins engine barring tool 3824591
- \*Chrysler/Miller engine barring tool 2747113

\*As a substitute for the engine barring tool and W' drive tool you may wish to use a 22mm socket and the engine's alternator nut, or a 15mm socket and the crankshaft vibration damper bolts to turn the engine. These methods are described in step 2.

Step 1: Use a 15mm wrench to remove only the number one (cylinder closest to radiator) individual valve cover. Depending on age/brittleness/previous maintenance, the valve cover gasket(s) may be reused. If replacement is necessary, the Cummins part number is 3902666. Price \$3.45 each (you'll possibly need six).

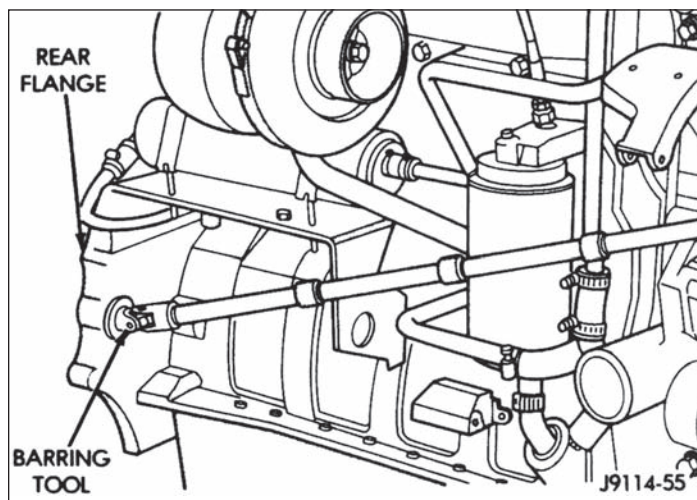
Step 2: It is time to locate the Top Dead Center for cylinder number one. The by-the-book method would have you using the engine barring tool. Remove the plastic cap (passenger side of engine) to gain access to the flywheel teeth. Insert barring tool and socket drive/extension. Bar the engine over while you reach for and push in an engine-timing pin. Where is the timing pin? It's on the driver's side, below the fuel pump on the backside of the gear case housing.

Is it easy to push the pin into its engagement hole? No. Is it easy to bar the engine over while engaging the pin into the hole? IMPOSSIBLE!



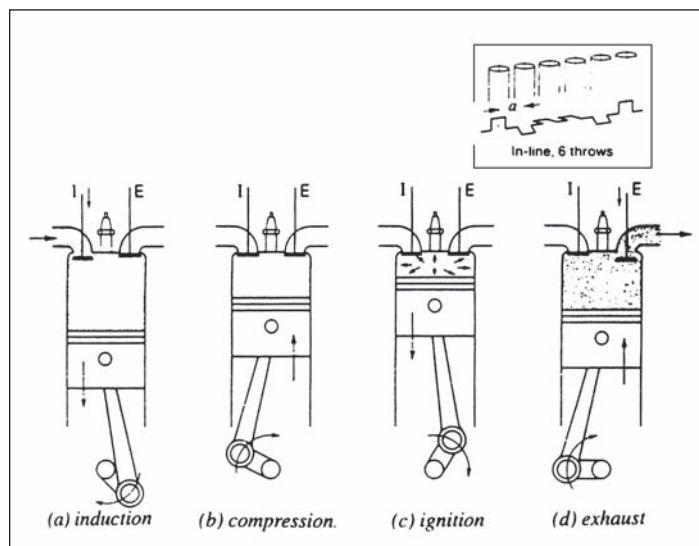
Many resourceful mechanics and members have shortcuts to the use of the barring tool/timing pin. Using the 22mm nut on the alternator or the 15mm bolt holding the vibration damper to the crankshaft are ways to turn the engine. The engine, when viewed from the front, should be rotated clockwise. I've tried the alternator trick. There is belt slippage when going clockwise. Counter- clockwise it's easy to spin the engine, but you'll have to think backwards if using the valve overlap method described below. If you prefer to stay in a clockwise rotation use the barring tool or the 15mm vibration damper bolts. If you use the vibration damper bolts the first valve adjustment is a two person affair; one below the deck to turn engine over, one above to watch valves.

Personally, I vote for the 22mm alternator nut/backward thinking method of engine rotation shown below.

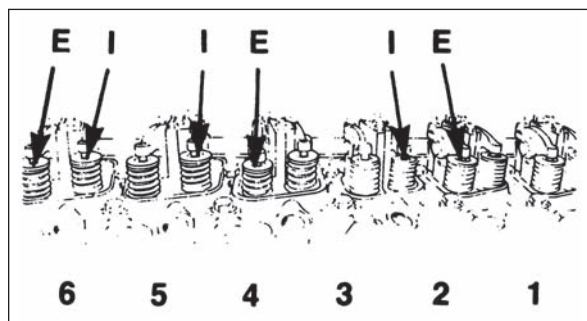


Regardless of your engine rotation method I'd like to share with you some "Shadetree" voo-doo magic that will cut your time under-the-hood significantly. *Unlike* fuel pump timing, *approximate* top dead center is all that is necessary for a valve adjustment. If you've tried to locate, much less pushed the timing pin to the tightly toleranced cam gear to find top dead center you'll know the procedure ranks up there in frustration with the first fuel filter change. To insert the timing pin you'll need the patience of Job, the finger dexterity of a 10-year-old, the thumb to forefinger strength of Samson, and the callused hands of a brick layer.

The voo-doo method for top dead center location is called “valve overlap.” Take a minute to think about a six cylinder engine and the operation of the pistons to top dead center. Pistons in cylinders one and six are “companions,” they’re both going up and down at the same time. Imagine that piston one is on the exhaust/intake stroke, while six is on the compression/power stroke and vice-versa. Knowing that one and six are companions, I want you to remove the valve cover to cylinder one (the cylinder closest to the radiator). Using your preferred method, rotate the engine to watch the valve action of cylinder one.



Now, think about the movement of the valve train and the four stroke cycle. Starting with the intake of air...hold it. Back up just a bit. As the piston is traveling to the top, it is pushing exhaust gases out of an open exhaust valve (rocker arm down). As the piston nears the top of the stroke, the exhaust valve is closing, the rocker arm is becoming horizontal. At the top of the stroke there is a slight bit of “valve overlap,” as the exhaust valve closes and the intake valve starts to open from its horizontal position. You’ve found the piston at the top of its exhaust/intake stroke. Rock the engine counter clockwise to affirm the overlap condition. Pistons one and six are at the top of their respective strokes (one is on exhaust/intake stroke, six is at the top of compression and in “firing” to make power). Piston six is at the official “top dead center” location. Skeptical? Remove the number six valve cover and check to see that the valve rocker arms move freely. Remove the other valve covers and you’ll find loose rocker arms throughout the valve train. *Only* adjust the valves as shown in the following diagram.

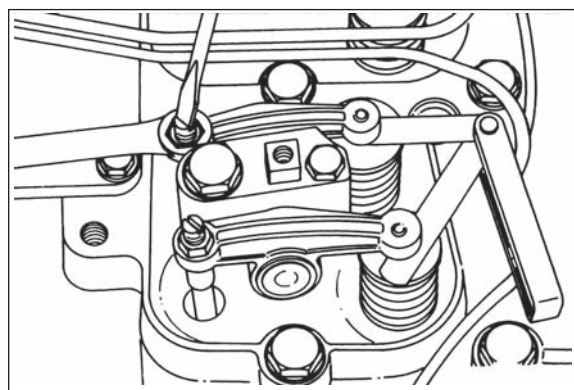


Intake Clearance: 0.254 mm [0.010 in].

Exhaust Clearance: 0.508 mm [0.020 in].

Check/set valves with engine cold – below 60°C [140°F).

**NOTE:** The clearance is correct when some resistance is “felt” when the feeler gauge is slipped between the valve stem and the rocker lever.

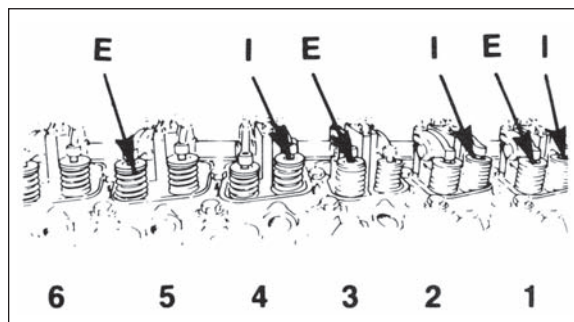


Adjust the valves as indicated in the illustration.

Tighten the lock nut and measure the valve lash again.

**Torque Value:** 24 Nm [18 ft-lb)

Mark the crankshaft damper to the engine oil pan. Rotate the engine 360°. As you come close to your TOG mark watch for valve overlap on number six (this is a method affirmation exercise). As the mark came up so did the “valve overlap” on number six, didn’t it? Again you’ll find loose rocker arms throughout the valve train, specifically the number one cylinder which is now on its compression/firing stroke. Only adjust those shown in the diagram below.



Members, please write us if you have any questions about the valve overlap/voodoo magic. Now that you’ve accomplished a valve adjustment you are “authorized” to comment on the necessity of doing the valve adjustment at future 24,000 mile increments.

# Injectors

ISSUE 72

## INJECTORS FOR 2003 AND NEWER HPCR ENGINES

by Joe Donnelly

The editor called with the assignment for this issue, "I want an all-encompassing article on fuel injectors for the 2003-and-newer engines that use the high pressure common rail (HPCR) fuel system. Can you do such?"

I asked for a little guidance: where to start, what to say. His recommendation, "Think about country music. Haven't you heard that David Allen Coe song where he sings about the 'perfect country music song?' I want you to do the perfect injector article—an article that is timeless and, much like the 'perfect fuel transfer pump' article that was written in Issue 56, one that Turbo Diesel owners can reference time and time again."

So, I looked back at Issue 56 and read, once again, about the low pressure fuel delivery/fuel transfer pump systems used on our Turbo Diesel trucks. Four years later, other than the price and availability of parts, nothing has changed in the fuel transfer pump saga.

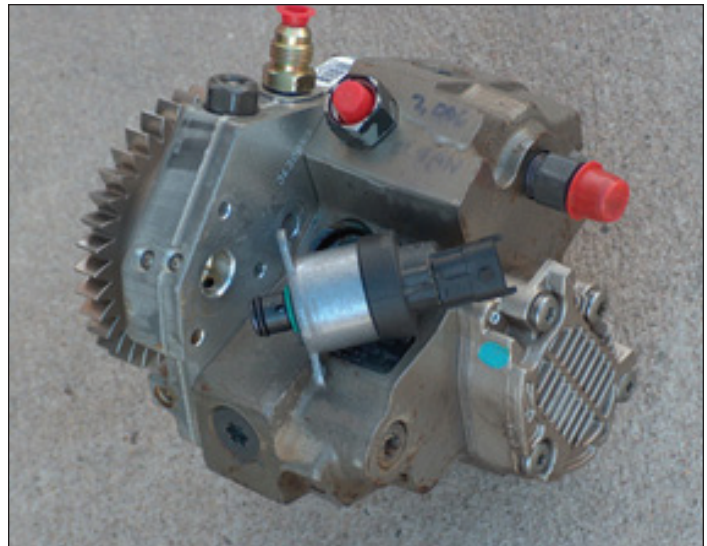
The following is my attempt to cover injectors that are used on 2003 and newer high pressure common rail (HPCR) engines. Below is an outline of the topics that will be covered:

- Principle of operation
- Related discussion in previous magazines
- Aftermarket processes
- Upgrades and preventing failures
- Inside the Injector
- The fuel transfer pump
- Frequently asked questions
- Injector removal and replacement

### Principle of Operation

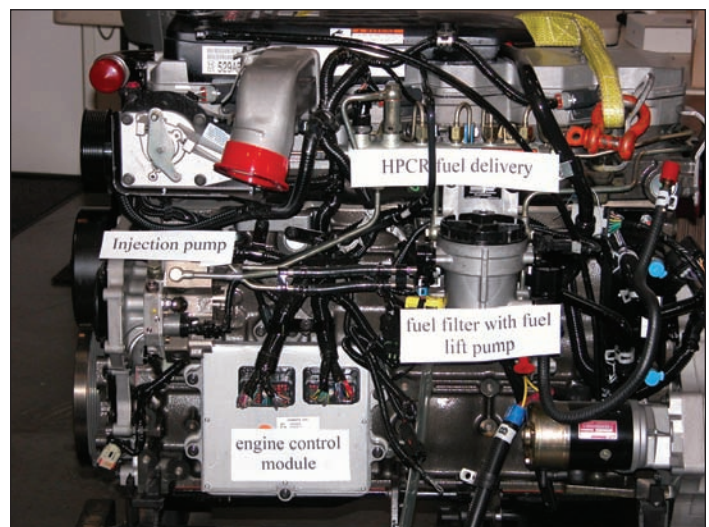
Over the past nine years, many of us TDR members have been introduced to the new high pressure, common rail (HPCR) fuel system used on the 2003 and later model year Cummins B-series engines. For example, way back in Issue 38, G.R. Whale mentioned the HPCR system and its multiple fuel injection events for a single cycle and Robert Patton quantified the quieter character of the new engine in the Ram. A few characteristics of the HPCR fuel system were mentioned in Issue 39, page 24.

Formerly, the '98.5-'02 24-valve Cummins engine relied on the Bosch VP44 pump to pressurize and distribute the fuel to each cylinder. These tasks proved difficult to accomplish with a single, compact unit, and durability was less than optimum. For the new HPCR engine, Cummins is again using a Bosch fuel injection system, but this time the high pressure pump does only that one thing—pressurize fuel.



**72i1 The rear of the Bosch CP3 high pressure pump showing the finned cover of the gear type pump at lower right. The Fuel Control Actuator is lying on the pump and attaches on the rear left side of the pump.**

This is a much simpler task and high pressure pumps are matured products. They can readily be made both durable and reliable. The Cummins electronic control system (ECM or engine control module) is also a proven electronic product.



**72i2 The driver's side of the 2003 HPCR Cummins engine. The injection pump, engine control module (ECM computer), HPCR fuel delivery system, and fuel filter with fuel "lift" or transfer pump are labeled.**

The HPCR injectors are electrically opened and closed. Pressurized fuel is fed to both sides of the needle-and-seat control shaft, so the solenoid does not have to be very powerful, which would be required to overcome a high pressure differential if only one side of the needle valve were being fed fuel.



**72i3 Bosch injector for the HPCR system.** The extra height of the injector for the new common rail system, compared to older style mechanical injectors, accommodates the electrical control mechanism to open and close the injector. Prior designs on our Turbo Diesels used fuel pressure to open and close the injector.

Electrically operated injectors have been commonplace for a couple of decades in gasoline engines. Again, the technology is reasonably durable and reliable, in addition to being the only practical solution to federal and state emissions mandates.

In Issue 40 we were introduced to the HPCR engine from an emissions perspective. The HPCR system has a rail pressure of up to 23,200 psi (1600 bar). The multiple injection events under such high fuel pressure result in a reduction of 8-10 decibels of noise. Improved injection timing and pilot injection widens the peak torque band by 400 rpm compared to the earlier '98.5-'02 24-valve engine with the VP44 injection pump. The high pressure pump supplies fuel to the injectors through the common rail.



**72i4 The high pressure fuel rail with the pressure relief valve** above it on the left. In the center are the shortened wrenches used to remove the #6 fuel line while clearing the cowl of the truck. The #6 line is threaded into the rail and an injector connector tube.

The injection event is controlled by the engine control module. With the previous Turbo Diesel engines ('89-'93 Bosch VE fuel pump; '94-'98 Bosch P-7100 fuel pump and '98.5-'02 Bosch VP44 fuel pump), fuel pressure pulses control the injection events. The HPCR fuel system gives higher peak cylinder pressures, so the engine block was strengthened and stiffened with sculpted side walls, stiffening rails, and a stiffener plate across the oil pan surface, just below the main bearing caps.

The HPCR system consists of five main components: electronic fuel lift pump, fuel filter and housing, fuel pump and fuel pump gear pump, fuel rail, and fuel injectors. Fuel travels from the fuel tank to the fuel "lift" pump which pressurizes the fuel to about 10 psi. The fuel then enters the fuel filter, and next travels to the high pressure pump (CP3). A gear-type fuel pump under the finned cover on the rear of the pump raises fuel pressure to 80-180 psi. The fuel from the gear pump is then supplied to the electronic fuel control actuator (FCA). The electronic fuel-control actuator (FCA) is an electronically controlled solenoid valve. The ECM controls the amount of fuel that enters the high pressure pumping chambers by opening and closing the electronic fuel-control actuator based on a demanded fuel pressure.



**72i5 The electric fuel transfer (lift) pump used from 2003-4 is on the side of the fuel filter canister that faces the rear of the engine.** The 2005-up models use a fuel transfer pump mounted inside the fuel tank.

The Bosch high pressure CP3 fuel pump (see picture 72i1) is mounted with three studs to the rear of the front gear case of the engine. The fuel pump is gear driven at a 1:1 ratio with the crankshaft; however, it is not timed to the engine. Therefore there is no need for a key-way in the drive gear. The gear is attached with a nut and washer. The CP3 fuel pump uses an O-ring seal to contain engine oil inside the gear case, where it mounts on the gear cover. Prior design fuel pumps were driven at camshaft speed (one-half of engine speed). The new gear case is also different in that it is indexed to the engine block by two dowel tubes inside the bottom two mounting bolts. There are no dowel pins for indexing the gear case, as was done previously. Hence, the concerns about the "killer dowel pin" (a potential problem with the previous engines '89-'02) falling out onto the gears do not exist for the new engine.

The pressure sensor on the fuel rail monitors the actual fuel pressure and sends an electrical signal to the ECM. When the actuator is opened, the maximum amount of fuel is being supplied to the high pressure pump. Any fuel that does not enter the high pressure pump is directed to the cascade overflow valve. The cascade overflow valve regulates how much excess fuel is used for lubrication for the pump and how much is returned to the tank.

The fuel that enters the high pressure CP3 pump is then pressurized to between 300-1600 bar (4,251-23,206 psi) by three radial pumping chambers. The pressurized fuel is next supplied to the fuel rail.

Fuel is pressurized in the CP3 fuel pump to a maximum of 1600 bar (23,206 psi) and then travels through the fuel rail supply line to the fuel rail. The fuel pressure at the fuel rail is monitored by the rail pressure sensor. If the pressure becomes excessive, the pressure limiting valve opens and vents excess pressure to the fuel drain circuit.

High pressure fuel then travels through the injector supply lines and through a high pressure connector. The high pressure connector contains an O-ring and locating pins. The high pressure connector pushes against the injector body when the high pressure connector nut is tightened. The injector supply line is then connected to the fuel connector. The connector tube O-ring seals returning fuel from leaking to the outside of the engine.

As mentioned earlier, the engine control module controls the fueling and timing of the engine by actuating the solenoids on the injectors. An electronic pulse is sent to the solenoids to lift the needle and start the injection event. By electronically controlling the injectors, there is a more precise and accurate control of fueling quantity and timing. Also, multiple injection events can be achieved by electronically controlling the injectors. For the HPCR engines, a pilot injection event is used before the main injection event to minimize noise, improve emissions, and improve cold starting. The familiar engine block heater is now an option because pilot injection is so effective for cold starts that it may be sufficient down to -40 degrees Fahrenheit!

The rocker housing is located on the top of the cylinder head. The 2003-2005 rocker housing has three pass-through connectors which connect the ECM wiring harness to the fuel injector wiring harness.



**72i6** The rocker lever housing installed on an engine, with injector wiring shown for cylinders 1-3.

The 2006-2007 rocker housing uses a single multi-wire connector to the ECM wiring harness. The fuel injector wiring harness then connects to the fuel injector solenoid posts. The housing is two-piece, with the lower piece remaining on the engine for normal maintenance operations. The black plastic cover on top of the aluminum rocker housing shrouds the crankcase breather system and its filter on 2003-2005 engines. The 2006-2007 engines use a one-piece molded plastic valve cover with integral filter/breather.

The fuel drain circuit incorporates several fuel return paths. As the fuel travels through the fuel filter and on to the CP3 fuel pump, a portion of the fuel flows through a passage in the fuel filter housing and into a fuel drain line back to the fuel tank. The fuel that flows to the CP3 fuel pump is pressurized and sent into a passage in the fuel pump. At this point, the fuel is channeled into two passages. One passage sends fuel to the electronic fuel control actuator and the other passage sends fuel to the cascade overflow valve. The cascade overflow valve sends some fuel to a lubrication passage which is used to lubricate the fuel pump, and the rest of the fuel is sent to a drain passage which connects to an external fuel line that is connected to a fuel drain circuit via the fuel filter housing.

At the fuel injectors, the fuel that is not injected is used for lubrication of the injectors. This fuel then travels through an internal passage to the rear of the cylinder head and into an external fuel return line. This fuel line connects with the other fuel return lines to make one fuel return line that returns fuel to the fuel tank.

The blow-off or "safety valve" on the top side of the common rail is set at 28,000 psi, whereas stock rail pressure is kept to about 23,000 psi. If pressure goes too high, the blow-off valve releases pressure and must be replaced because the check ball and its seat will become etched and no longer seal. As we look back to 1989 and the VE pump with about 10,000 psi, the P7100 with 16,700 psi, the VP44 with 14,500 psi, and now the HPCR with 23,000 psi, we see that higher injection pressures have increased fueling and power and improved fuel atomization for lower emissions.

### Related Discussion in Previous TDR Magazines

Over the years, diesel fuel injectors have had to deal with increasing system fuel pressures to improve atomization of the fuel for decreased exhaust emissions. Corresponding to the increases in pressures and emissions regulations, the injectors have been built to ever tightening specifications, including tighter clearances (millionths of an inch). The older 12-valve engines and the early 24-valve engines (up to 2002 model year) used mechanical injectors. These units use a stiff spring to hold the metering "valve" closed until the injection pump sends a high pressure pulse of fuel through the line to the injector. Beginning with the 2003 model year and the HPCR engine, substantially higher injection pressures were incorporated into the system, along with a major change in how the injectors were opened and closed. The new high pressure common rail (HPCR) is kept at high pressure from a simple pump whenever the engine is running. Thus, the injectors always have a high pressure fuel "pulse" at them, and they are now opened and closed electrically. This change also allows the engine computer to open and close the injector more than once during a "firing" event. With the 2003-2004 HPCR engines, a small injection occurs first, just before the main injection event. The early pulse is a major contributor to the quieter operation of these HPCR engines

compared to earlier engines. For emissions reasons, later engines, the 2004.5 to 2007 model years, went to a total of three injections per firing event. In 2007.5 and later models (the 6.7-liter engine) four injections are used.

Since the focus of this article is a comprehensive look at the HPCR fuel system, there are other removal and installation articles you may want to reference. The following is a comprehensive listing:

- Injector installations, 12-valve, 24-valve, and HPCR were covered in TDR Issue 51, page 94.
- A slightly different approach for removal and installation was presented by TDR member Stan Gozzi (SAG2), which follows the Cummins and Chrysler procedures and uses the special Cummins tools, is found in TDR Issue 52, page 46.
- Scott Dalglish visited Dynamite Diesel Performance (DDP), a high quality aftermarket injector shop, and discussed their injectors in Issue 56, page 96; Issue 59, page 86.
- Common rail injector lines #4 and 6 have experienced failures. An updated line with a hold-down bracket was covered in Issue 56, page 108. (see photo 72i7).
- HPCR topics have been covered in the "Have Ram Will Travel" column several times, including Issues 56 (CP3 installation), 62, 63, 69 (injectors)
- Andy Redmond discussed hard starting problems and low fuel pressure testing in Issue 66, pages 124-125.

And, to meet the objective of my assignment, at the end of the article I'll again cover the removal and installation procedure, complete with updates that I've learned through the years.

Overall, high quality aftermarket injectors are a significant and valuable component of a well-balanced hop-up strategy. These injectors are more involved to install than on earlier trucks. I have found that Stage 1 injectors (50-60hp gain) are a good, moderate compromise, suitable for daily driving, towing, and performance. At a small sacrifice in fuel mileage, Stage 2 injectors may be substituted (DDP Stage 2 injectors are good for a 90hp gain). Stage 1 injectors of the quality supplied by DDP and a few other vendors give similar mileage to stock injectors, or in some driving conditions, a little better than stock.

### Aftermarket Processes

#### Extrude Honing

This process was popularized and refined for injectors by Diesel Dynamics more than a decade ago, and is now carried on by Dynamite Diesel. A very fine abrasive slurry is pumped through the injector nozzle under pressure. Done properly, the seat for the pintle (needle) is not "washed out," but the entrances and exits of the holes are slightly rounded, and the cutting marks inside the holes are smoothed. The offset holes in the photo on the computer screen shows that they happen to be older 12-valve Bosch/Cummins nozzles, with 5 holes as is the case for the 12-valve applications. This computerized endoscope (borescope) from Karl Storz "looks" at the inside of an injector nozzle for quality control. The DDP test procedures for all their injectors includes using their Hartridge test bench, which allows them to meet and exceed the specifications by Bosch. DDP looks at such parameters as fuel delivery flow rates under idle, mid range, and full power conditions, backflow and

leakage, and response time. When a HPCR injector fails, it can be something that needs immediate attention. You don't want a crankcase full of diesel fuel, a dead miss, or clouds of white smoke with the attendant washing of lubrication from the cylinder walls. More on injector failure later in the article.



**72i8 Borescope on-screen view of the inside of an extrude honed 12-valve injector nozzle**



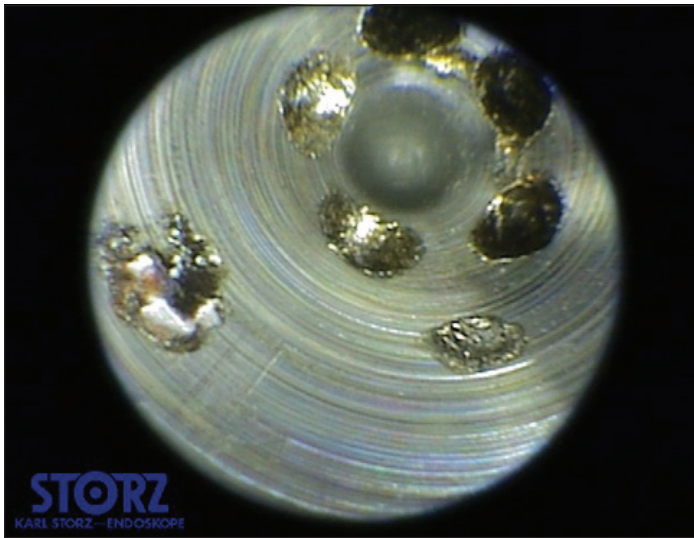
**72i9 Hartridge injector tester to determine leakage, flow rate, and response time**

DDP Injectors use Extrude Hone Technology. They start with Bosch EDM'd nozzles with the correct spray angle, and finish hone them to remove imperfections, polish the inside of the nozzle, and radius the inside of the holes where the fuel flows. This leads to better atomization, which provides less smoke and heat, and more power and mileage. DDP hones each nozzle separately and balances their flow to closer than factory specs to create a smooth idle, and smoother running truck. Stock injector nozzles from Bosch are usually within 2 to 3 liters per minute on a flow test machine. When

any set of nozzles leaves DDP, it will be within 1 liter per minute.

### Electrical Discharge Machining

An alternative to the extrude hone process for making higher fuel flow nozzles is electrical discharge machining (EDM) wherein electrical current is used to burn precise holes through the steel tip of the nozzle. Done properly, this process is not only good, but the way Bosch originally makes the holes in their nozzles. The nozzles are high quality steel and the small drill bits (around .007" to .012") that would be needed would be too fragile to make drilling the holes practical. Done poorly, EDM can result in poorly shaped, poorly spaced holes with burns in the steel inside the nozzle, even at the seating area for the pintle.



**72i10** Borescope view of a poorly manufactured nozzle by an EDM process

Bosch uses EDM to create nozzles, but on a very advanced machine that controls the angle and speed of the wire insertion. The correct angle of insertion is very important or the spray angle will be changed, resulting in possible engine damage. When Bosch changes the speed of insertion, they can achieve a cone shaped hole that will improve atomization. EDM's used in the aftermarket are usually decommissioned medical instruments that do not have the ability to control either angle or speed precisely enough to create a quality product. EDM that is done by Bosch is followed by abrasive flow machining, to clean up any imperfections, remove burn residual and balance injector flow. Aftermarket EDMing does not use abrasive flow to balance flow or clean up any imperfections.

### Injector Upgrades and Preventing Failures

In Issue 56 (page 96), Scott Dalglish discussed his results with Dynamite Diesel Performance (DDP) injectors on his Third Generation Turbo Diesel. In his quest for mileage first, and power second, Scott chose a set of Stage 1 injectors. His article described the aforementioned extrude honing manufacturing processes and provided dyno results verifying the horsepower claims of DDP. He reported an increase in fuel mileage of 8%, not accounting for the approximately 7% loss he associated with the winter fuel he was using at the time. This comes out to about 1.5-2.5mpg, estimating conservatively. In Issue 59, Scott went to Stage 2 injectors and reported a 6% loss in fuel economy with them (compared to the Stage

1s) in Issue 60, page 84. Doug Leno gave us additional discussion and photos in Issue 57, page 45. He also chose Stage 2 injectors.

A couple of years ago, Bosch started supplying replacement HPCR injectors with Saleen coated steel bodies for better durability against cracking and some internal re-design to minimize sticking and erosion of the fuel return seat. This photo shows six new DDP Stage 1 injectors with shiny white coated steel bodies, and facing the other way is a used injector with the regular gray colored steel body.



**72i11** Six new DDP Stage 1 injectors with the new Bosch shiny white coated steel bodies. Facing the other way is a used injector with the regular gray colored steel body.

I have seen various types of injector failures, particularly on HPCR Turbo Diesels with over 150,000 miles. As I mentioned before, they cycle two times per firing on 2003-2004 engines. They cycle three times per firing on 2004.5 through 2007 engines, and four times on the new 2007.5-up engine (6.7-liters). Fuel pressures are higher, so any tiny residual particulates are more abrasive than on earlier engines. It is not reasonable to expect them to last as long as 12-valve or 24-valve injectors. While "chatter" during the fuel pulse made mechanical injectors wear faster than you might think for one cycle per injection "event", the springs were durable. In comparison, the HPCR's electric solenoids are things with "minds of their own" and as you know, electrical stuff can fail at a moment's notice. These solenoids, along with varnish on the pintles that causes sticking, have become significant sources of high-mileage failure on HPCR engines. The dirtier the fuel (3 micron filtration is the way to go, and FASS offers such a filter) and the higher the rail pressure, the faster the injectors wear out. Some folks who advocate using poorly filtered "additives" such as used engine oil will have problems.

Injectors are more complex and clearances are tighter to work with higher injection pressures and meet ever stricter emissions regulations. Our usage habits have to be consistent with these changes. We could "get away with" some practices such as iffy fuel, high EGT, and "neighborhood/farm shop" modified injectors with the old engines. We need to use cleaner fuel (no used motor oil, please, on HPCR engines). If that engine oil was too used up and filled with wear metals for your engine bearings with .005" clearance, why should you add some to your fuel, and use it in a fuel injection system with 25 millionths of an inch clearances? You also will want to use better fuel filtration, moderate your EGTs, and keep

fuel rail pressures closer to stock. The new engines will respond to modifications with more power than ever before, but to get the longevity and reliability you want, you have to practice moderation.

When a HPCR injector fails, it can be something that needs immediate attention. You don't want a crankcase full of diesel fuel, a dead miss, or clouds of white smoke with the attendant washing of lubrication from the cylinder walls. Cummins does offer a rail plug to deactivate one cylinder for test purposes. It is not suitable for extended use, such as getting home pulling your trailer. You ask, "Why not?" First, the injector that is capped off will fail completely within a few minutes due to lack of lubrication and cooling. Second, if one injector is bad, others are most likely going to follow suit. The vibration and harmonics will likely damage the balancer, clutch, transmission, and engine bearings. In a desperate situation, capping one cylinder of the rail for a brief time could be justified. If the cause of the problem is a cracked injection line (usually #4 or #6), it would be much better to carry replacement lines and replace the line immediately.

Again, DON'T add used engine oil, transmission fluid, and other junk to your fuel just because an old-time trucker said to do so! Stan Gozzi of Chrysler related to me how a fuel shop technician told him to paint the pintle of an injector with a Magic Marker and then try to replace the pintle into the nozzle. It won't fit because the clearance is too tight. If you force the pintle (needle) into the nozzle, you will wipe off the Magic Marker! That more viscous "stuff" that you add to diesel fuel will cause problems. As I related in Issue 56 (page 103), particulates become more damaging/abrasive as fuel pressure increases, so the higher pressures and tighter fuel system clearances (to prevent excessive leakage of fuel between parts) make better filtration essential in the newer Turbo Diesels.



**72i12 Pintle with Magic Marker stripe, showing inadequate clearance for the nozzle.**

Water in the fuel system remains a major source of problems. Here you can see a rusted but cleaned up injector connector tube above a good tube. Imagine how much rust can be found inside the rusted tube, rust that will be sent to the injector.

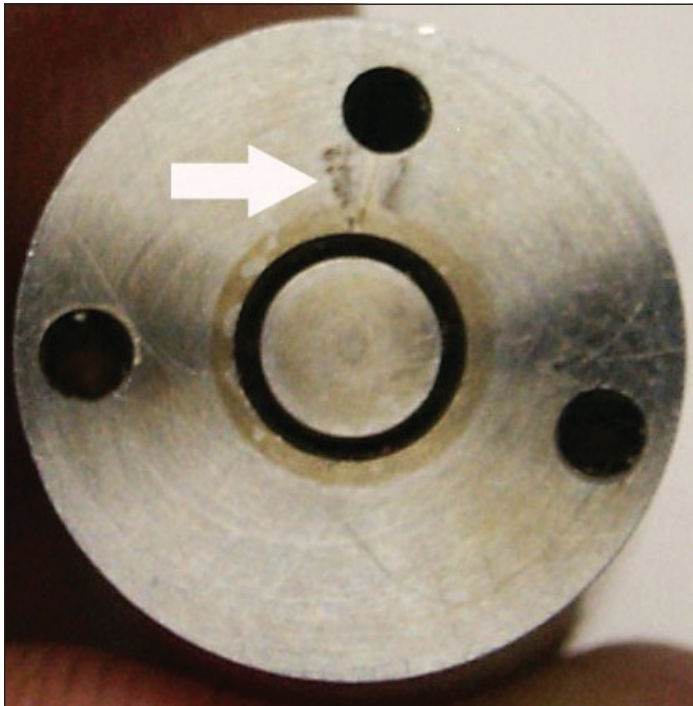


**72i13 Rust pitted connector tube above a good tube.**

For preventive maintenance, I purchased a completely new set of injectors at about 100,000 miles. Like the two other TDR writers, Dalgleish and Leno, I asked Lenny Reed of DDP what would give the best mileage. He recommended his Stage 1 over anything else, including stock. In the future, since I use only high quality fuel and a 3 micron filter, and have not raised rail pressure nor run high EGT, I believe I can extend the safe service interval for my injectors significantly. Cost for parts (six injectors) will typically run around \$2000 for rebuilt injectors, up to \$2700-\$3000 for new stock or Stage 1 units. Installation should take about eight hours. Sometimes injector problems will be reported by the engine's ECM as diagnostic trouble codes, but often diagnosis is a matter of careful thinking. First replace potentially relevant, less expensive parts such as the FCA, pressure sensor on the fuel rail, and pressure relief valve. The nature of the problem you have should be considered against the roles these parts play. Hard starting could be caused by these parts, for example, or by excessive fuel return from worn and eroded check balls and seats in the injectors. White smoke at idle is most likely caused by cracked injectors or sticking pintles. Violent rattling at idle and difficulty in maintaining idle is most likely the FCA or possibly the pressure sensor. If you have been experimenting with fuels or additives, have stacked pressure and other fueling boxes, and/or have big power upgrades with the stock turbo, you are probably a candidate for new injectors. If you just don't have very good luck, it might be injectors. Do yourself a big favor. If you added ATF or some other "mouse milk" on the advice of that old-time trucker, completely drain and flush the entire fuel system, and replace all the filters before installing new injectors. If you like that big power, get enough turbocharger/s before using it with the new injectors. It is far easier to make big power with the HPCR engines than with earlier versions, but remember that you can add power/fuel and increase EGTs with no warning until it breaks or melts. The faithful Cummins will pull harder and harder upon your demand, even if it kills itself.

Very high rail pressures (from pressure boxes mostly) and very high EGTs contribute greatly to cracking and wear of moving parts inside the injectors. Only after the injector is disassembled can you see the cracked nozzle and cracked body. It is easy and relatively cheap to add electronic power-adders, without taking adequate steps to control EGTs. You are just a click away from taking the rail pressures so high that you will sooner or later "blow" the pressure

relief valve on the fuel rail. If your truck is hard to start, that may be the reason. High rail pressures are also resulting in greatly increased injector failures. Any contamination in the fuel becomes much more abrasive at higher injection pressures, necessitating better fuel filtration. Think of a water hose, then a high pressure nozzle on the hose, then a water jet steel cutter. It's all about pressure! I am running the FASS 200 lift pump system with 3 micron filtration, and use the stock filter canister with a 7 micron filter as "last chance" back-up. I have seen a lot of injectors with failures at the nozzles and the injector bodies from high rail pressures and high exhaust gas temperatures.



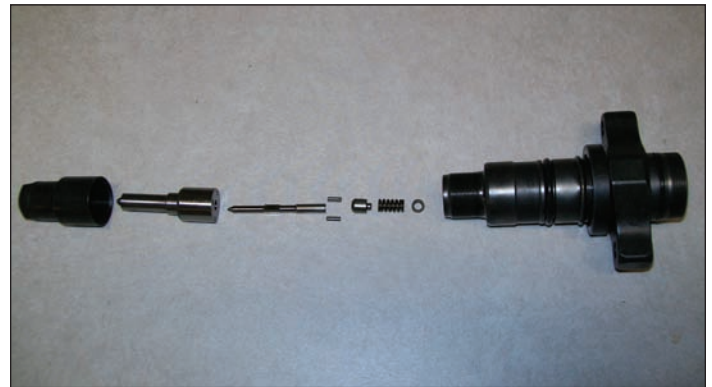
72i14 Cracked injector nozzle.



72i15 Cracked injector body.

### Inside the Injector

We have looked at the pintle and nozzle with the remarkably tight clearance between them. Here are the components of the HPCR injector, first the bottom half with the nozzle nut, nozzle, pintle, and the main body to the right. Next is a photo of the top half with the armature to the left, check ball and seat in the center, and the solenoid and its nut to the right. Next is a close up of the armature that was on the left of the preceding photo. You can see the buildup of sludge on it from contaminated fuel. Finally, on a one-inch wide block you can see the fuel return seat, ball check (.053" diameter) and the end of the armature that fits to the fuel return check ball. A technician needs 500x magnification to inspect the ball, cup, and the seat in the armature for wear or erosion.



72i16 Disassembled bottom half of HPCR injector.



72i17 Disassembled top half of HPCR injector.



72i18 HPCR injector armature showing built up sludge.



72i19 Fuel return seat, check ball, and end of armature.

### Fuel Transfer (lift) Pumps

The electric fuel transfer pumps used in 2003-2004 engines [photo 72i5] may not be adequate for more than a gain of about 60-70hp over stock. The in-tank 2005-up lift pump has a slightly better reputation for fuel delivery and a noticeably better reputation for longevity. These lift pumps were covered in detail in Issue 56, pages 60-74. If your Turbo Diesel comes with an electric lift pump, add a spare to your "boonie box" and monitor the performance of your lift pump with an electric gauge (so you won't have diesel fuel in the cab). There are also aftermarket lift pumps, with or without extra fuel filtration. The FASS 200 gallon per hour lift pump and filtration system was described in Issue 56, page 102.

The EGT range of most Turbo Diesel engines with stock turbos likewise may or may not remain safe with up to 60-70hp more, depending on load, altitude, ambient temperature, etc. However, these two components may be closer to "maxed out" with typical hop-ups on newer Turbo Diesels than the older trucks were. In part this is because the older trucks started with lower horsepower levels. Check your fuel pressure gauge and see if the lift pump pressure stays around 5 psi or so under full power. See if EGT get too high under full power and and/or heavy loads. Maximum EGT is 1450° for 2003-'04 and 1500° for 2004.5-up engines. For safety, it is a good idea to stay well under these maximums, particularly for long pulls. With my BD compound turbochargers and intercooler, I can keep EGT below or at 1100° towing a 5000-pound trailer in the mountains at higher altitudes and 70-75mph.

### Summary

In summary, the enemies of the HPCR fuel system are dirt, water, contaminated fuel, and excessive rail pressure. Have we covered everything you need to know? Not quite yet, let's answer some questions and then finish the article with the removal and installation procedures.

### Frequently Asked Questions

#### Rail Pressure versus Fuel Mileage

**Q:** In Issue 63, page 82, writer Joe Donnelly did an article about the 2003 and newer ECMs and reprogramming them using a "Smarty" by MADS Electronics. In that article we are told that added rail pressure does not give mileage gains and is "problematic to injector and injection system durability." Then on page 110 there was a "Product Showcase" article where we are led to believe that increasing fuel pressure will increase mpg by 7%. What is the story?

**A:** In theory, it would seem that increasing rail pressure would help mileage, as noted by writer Gary Wescott in his "Product Showcase" about the Edge products' Mileage Max product on page 110. In practice, neither Marco Castano (owner MADS, electronics/developer of Smarty), Mark Chapple (owner of TST, Cummins engineer for 33 years, developer of Power Kit and PowerMax products), nor I have seen any clear, verifiable mileage increase from raising rail pressure above the stock Cummins curve. Power adders do "cheat" the truck's overhead console report of fuel mileage, giving falsely high readings because fuel is being added that the computer doesn't know about. Mark Chapple told me he did see a nice torque increase in the 900-1300 rpm range from added rail pressure that was not achievable to the same extent by adding injection duration. As with some other products and approaches to modifying turbo diesels, "YMMV" in internet slang, or "your mileage may vary." Remember that the Turbo Diesels with the lowest injection pressures, the First Generation trucks, were renowned for giving good mileage. (Then again, they were only rated at 160 horsepower/400 torque and the truck itself was much lighter.)

Finally, in another one of those all-encompassing articles, see the Turbo Diesel Buyer's Guide, pages 80-99, "So You Want Fuel Economy," for the bottom line on YMMV information.

#### Preventive Maintenance?

**Q:** What should I do for preventive maintenance on my 2006 Turbo Diesel? I have heard of many injector problems. Do I need a better fuel filter set up?

**A:** Here are some general things, my opinions:

- Keep exhaust gas temperatures down; I like to keep EGT under 1300° even though you can get away with a bit higher. Dropping a valve seat is expensive, and that is what usually happens first after a number of high EGT "excursions."
- Change the oil regularly, using CI4+ rather than the newer spec CJ if possible. I like to change it at 4000-4500 miles.
- Keep rpm under 3000, but don't lug the engine and drivetrain under high power below 1800rpm.

- If you raise rail pressure with a “box” or program, you should improve fuel filtration; 3 microns is a good level. Otherwise, you will probably be okay with the stock 7 micron Fleetguard filter. I like the FASS for its reliable fuel transfer pump and good filters.

### Finding the Bad Injector

**Q:** My Turbo diesel has a lot of timing rattle noise and rough acceleration around 2000rpm under light throttle. When slowing down, the idle drops down to 500rpm and then recovers.

**A:** Since the truck is not lighting up the dash with diagnostic trouble codes, it is best to start parts-swapping with the least expensive items. Start with the fuel control actuator (FCA) on the back of the CP3 pump. The FCA is less than \$120.

Let's continue to discuss parts-swapping with the least expensive items. The following is a tip that I picked-up from TDR issue 62 where a TDR member wrote-in with a surging, rough idle and hard start problem. Unfortunately for the owner, he had already replaced the injectors, an expensive repair. The tip: “Try adding a couple of cans of ashless two-stroke oil to the fuel. If it clears up, it's a defective fuel control actuator (FCA). The oil lubricates the FCA and the engine will idle until the two-stroke oil is depleted. It's a cheap diagnosis method and only takes the time to run some treated fuel through it.”

Continuing from Issue 62, “I was told that adding a fuel lube to check the FCA was a test that STAR (Chrysler tech assistance) was using some time ago. A friend who had a Turbo Diesel with a sticking FCA added fuel lube to it by accident and the truck ran fine. After a tank and a half of fuel without the additive, the rough idle, stalling, and stumbling returned. He had problems similar to yours and everyone was telling him it was defective injectors. As long as he kept the fuel additive in the tank, the engine ran fine. He tried different fuel treatments including Marvel Mystery Oil. I read about the fuel lube test, STAR, and the FCA and told him to replace the FCA. He replaced the FCA and the truck has been running like new without any additives.”

The owner tried the two-stroke oil and the engine did not stumble, but it still idled rough. The dealership replaced the FCA and the problem with the engine was solved.

To check individual injectors on the '03-'05 Turbo Diesels, you could unplug one of the three electrical connectors at the head, while the engine is not running (the wires carry up to 50-volts). Once you see which pair of cylinders is at fault, you can remove the valve cover and remove one pair of wires at a time. Or, you could go right to the individual injector wires. You will get a trouble code, but you can remove it later. Since other injectors may be “weak” the best approach would be to send all six to a Bosch shop like Dynamite Diesel for testing. They are a Bosch dealer and could sell you new injectors as needed. Obviously, unplugging the injector will serve as a diagnostic method only if the electrical solenoid is at fault. If you have a mechanical failure, you would have to plug off one injector at a time or replace one at a time. DDP could test all six for you if that would be more convenient.

### Other Injector Symptoms

**Q:** What are some of the other symptoms that I have an injector-related problem?

**A:** Often a truck will idle and run rough like it is missing. If it shows a diagnostic trouble code (DTC) P2149-“Fuel Injector Group, 2 Supply Voltage Circuit,” you'll want to check for a fuel injector solenoid failure or the electrical connection through the valve cover gasket. To check for either problem, the valve cover must be removed.

Disconnect each injector in the bank affected which should be cylinder number 4, 5, and 6 and check the resistance with an ohmmeter. It should check less than 1-ohm and greater than 0 resistance. Look for the odd reading.

Disconnect injector harness outside the valve cover and using an ohmmeter, check each wire for continuity and resistance. The wires should be less than 1 ohm and greater than 0 resistance.

### Hard Start = Injector Problem?

**Q:** I have heard that an engine that is hard to start could signal a looming injector(s) problem. Can you explain?

**A:** Let's talk about the long crank issue. This is generally created due to the CP3 injection pump not being able to pump up enough pressure in the common rail to fire the injectors (around 5200psi). The first thing to check is the total fuel return volume to see that it doesn't exceed about 60ml. Sometimes you can cure the problem by re-torquing the fuel delivery tubes. Next, check the individual injectors to see that they are returning around 2-6ml. Any injector with a return volume in the 12-14ml range needs to be replaced. This happens when the check ball wears so that it doesn't seat correctly which, of course, causes a leak. To confirm the problem, with the engine cold, cap off each injector during cranking and see which one allows the engine to fire up.

I noted that TDR writer Andy Redmond had presented this Q&A back in Issue 66. The following is how he went about the diagnostics and repair:

“Recently, a 2005 truck arrived with a hard starting problem. Other recent repairs included two remanufactured injectors, but shortly after the injectors were installed the owner complained the hard start problem worsened as did his poor fuel economy. The scan tool was connected and no diagnostic trouble codes (DTC's) were present. The batteries were tested and found to have a good charge. My next step was to monitor actual and desired rail pressure (psi) during the cranking attempts. After several consecutive cranking cycles the scanner showed pressure increasing from 1000 psi to about 4,000 psi at which time the engine started. Why will the truck not crank until a certain pressure level is met? Simple. At low pressure the ECM programming does not command the injector solenoids to energize. A light misfire was observed at engine idle.

“The minimum rail psi for engine start is purposefully not stated. Depending upon the scan tool manufacturer and the ECM programming of desired rail psi, it will vary. Likely much of the variance is due to how quickly the scan tool can respond and display a value. I have not personally observed a truck that would start while cranking with less than 2,000 psi. Usually the range is often 4,300-5,800 on a known well running truck. Chrysler lists the rail operating pressures from 4,321 to 23,206 psi.

I suspected excessive injector return flow. Miller SPX service tool part # 9012 (see photo) was installed into the fuel return port on the right rear side of the fuel filter housing (item 4); then a length of fuel line was routed from the fitting to a five gallon diesel fuel can.



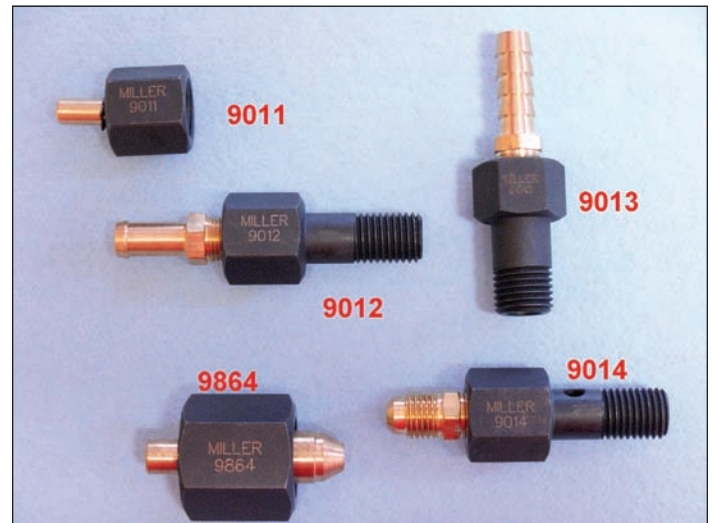
Looking at the 5.9 HPCR ('03-'07) fuel filter assembly:

1. Fuel supply line from the fuel tank to the fuel filter at the quick connect point
2. Fuel return line to fuel tank at quick connect point
3. Banjo bolt location for fuel rail and CP3 to return fuel to the system
4. Banjo bolt location for the fuel injectors to return fuel to the filter/fuel tank

Another length of fuel line was routed from the fuel return line to a calibrated container. The total return flow after the engine idles one minute should be 180 ml of fuel (or 6.1 oz.). This truck showed 443 ml / 15 oz. of fuel after the test. This suggests one or more injectors leaking into the return fuel passages (integral inside the cylinder head); improperly torqued injector connector tube retaining nuts (should be 37 ft-lbs); cracked injector body; or fuel leaking into the cylinders (usually causes white exhaust smoke), etc. The injection lines were removed and the connector tube nuts were retorqued. All of the retaining nuts were under specification, with the two at the recently replaced injectors being significantly less than the desired torque specification. Could the torque on the two injector tubes be the only problem?

The injector return flow test volume specifications/testing procedures have varied by model year and have been updated to include additional testing technique—such as the idle ramp up return test and the no start return test (see 2007, Factory Manual, TSB 14-003-06 and Warranty Bulletin D-05-24).

After the injection lines were reinstalled the return test was again performed. The truck started with fewer cranking attempts to build required rail pressure. But, it still wasn't right. The engine idled one minute and 325 ml / 11 oz. of fuel was measured in the container. This is still an excessive amount. Next the injector lines were removed one at the time and the Miller SPX tool # 9011 (see photo) was installed at the rail. The engine will run on five cylinders while one line is blocked. The engine was started for one minute with each line consecutively removed, then reinstalled to test each injector. The calibrated container was closely measured for return fuel after each individual injector was block tested. The reason for this process of elimination is to isolate one or more injectors that have excessive return. A good injector should reduce total flow by not more than 40 ml or 1.4 oz., while one that returns too much fuel will negligibly reduce total flow (provided only one or two of the injectors return excessively) when blocked off. No single injector seemed to be the major leak source. Therefore, replacement of the other four injectors was recommended. The total return flow returned to less than the 180 ml/6 oz. specification when retested. The truck built rail pressure quickly and started normally. The customer later stated that the "lost" fuel economy returned.



Miller spx specialty tools.

## Replace Injectors?

**Q:** My 2004 Turbo Diesel has 198,000 miles, but so far no injector problems. Should I replace the injectors now, or wait until I have a problem? They are expensive.

**A:** Perhaps some discussion about modes of failure would be in order here. As some feel, if things are fine, you don't need to change injectors. If you haven't added power, the mechanical aspects will be fine for a long time. As I mentioned, high exhaust gas temperatures and high rail pressures can cause damage. Cracks in the nozzles or bodies, and wear of the check ball and seat are two problems that can occur. On the other hand, failure of the electrical solenoid can happen any time.

Whether you want to incur cost now is up to you. I have heard of folks paying more for reconditioned injectors than what new ones can be bought for. I have heard of high costs at some shops for replacement, and have seen evidence of poor workmanship, leading to further problems. Therefore, you may have two reasons for performing preventive maintenance. You can choose the mechanic/shop and you can buy the latest, stainless steel injectors. On the other hand, you might be able to continue using your old parts for many more miles. Consider also your usage for the truck. If you take long trips through unpopulated areas, such as in the West, a failure could leave you stranded.

## What Does It Cost?

**Q:** Okay, let's get to the bottom-line: what is it going to cost to replace the injectors, and can I replace them as needed?

**A:** In the "Injector Upgrades and Preventing Failures" section of this article I briefly touched on the cost, but let me take this opportunity to be specific.

For the do-it-yourselfer the first time you remove and install an injector(s) can take a full 8-hour day. Subsequent R&I can be done in about 4-5 hours. So, time is money... what is the cost of shop labor in your area? What is your time worth?

Unfortunately it takes almost as long to change only one injector as it does to do all six. All types of intake plumbing, breather assembly, wiring, and injector lines have to be removed. So, outside of a low mileage, one-off kind of situation, or where you have a DTC telling you what to do, if an injector is giving problems and you've had a good service life from Day One, I would replace all six injectors at the same time.

Shops and vendors have been investing six-figure sums of money to be able to test injectors. Should you have the time to send out for test, this service is becoming more so available. Injector testing cost about \$50-\$60 per unit.

What about the cost of the replacement injectors?

The editor recently did a search using different engine serial numbers used in years 2003-2009 engines. Interestingly there are only three injector generations. I'll break those down, along with part numbers, for you:

| Bosch         | Cummins ReCon | Mopar     |             |
|---------------|---------------|-----------|-------------|
| '03-'04       | X0986435503   | 5254686RX | R 8004082AB |
| '04.5-'07     | X0986435505   | 5254688RX | R 5135790AE |
| '07.5-current | X0986435518   | 5253220NX | R 8069384AA |

How much do the injectors cost? On any given day you can search the internet and get price quotes from \$300 to over \$700 per injector. On any given day you can be bumfuzzled with hype and such by alligator-this and hot rod-that shops that claim to sell injectors. On any given day there is a shop or vendor that has invested six-figure sums of money for Bosch test stand equipment to check, test and remanufacture these injectors. On any given day there may be a short supply of injector units.

If you need injectors you'll want to deal with reputable sales agents. For your consideration: Mopar, Cummins, Cummins ReCon, Bosch accredited shops as recognized by the Association of Diesel Specialist ([www.diesel.org](http://www.diesel.org), page 137), TDR vendors and specialty shops.

So, as I mentioned before, the average price for a six-pack of injectors and their removal and replacement: \$2000-\$3000 for parts, 8 hours for labor.

Did you want a performance upgrade injector with your order, sir? How about an order of fries or a hot apple pie? (My attempt at being cute...)

## Stock or Aftermarket Injectors

**Q:** What is better, stock or aftermarket injectors to replace my leaking injectors? Can I replace them myself?

**A:** Dynamite Diesel has the Bosch injector testing equipment and gets the new stainless steel bodies when they get new injectors from Bosch. They recommend the Stage 1 over stock for performance and mileage. That is what I put into my Turbo Diesel recently. They provide complete installation instructions with color photos with their injectors. For the "how to" on injector replacement, I've updated the instructions that I wrote five-years ago in Issue 51 at the end of this article. Be sure the seating nipple end of the connecting tubes are smooth and are seated uniformly, and that the injector line ends are also smooth and corrosion free.

## Injector Removal and Replacement

### Tools:

You will need a few specialty tools to make the injector replacement easier. The aluminum plate at the top keeps the exhaust rockers in order and assembled. Under it at the left is a 15/16" socket cut down to 1" total length, with a connector tube nut in it. To the right of the nut is an orange painted tube that facilitates pressing the new injector into its well in the head. Next is a blue painted cover for the air intake hole after removal of the air horn. Over it and the aluminum plate is a 9" length of 3/16" brake line tubing and 1/4" OD vinyl hose for sucking diesel fuel from the piston bowl if some

drains in a cylinder after removing an injector. To the left is a "lady foot" pry bar to remove the injectors. It has red paint on it. At the bottom are a length of 5/16" pushrod with the open end partially squashed to retain a Q-Tip, and a modified rifle bore brush and rod for cleaning out the injector tip hole in the head. These tools are discussed below in more detail.



**72i20 Specialty tools for HPCR injector replacement.**

You can use a nut of M14 x 1.5 thread and a screwdriver to pull the connector tubes in the head. In most cases, the tubes can be pulled just with fingers on the threaded end, or by nudging them with a screwdriver blade on the threads. It is helpful to have a cut-off 5/16" hollow engine pushrod with the cut end partially flattened so it will hold a Q-tip tightly. This tool enables you to clean the sealing surface in the head at the bottom of the injector well.

You will use 3/4" (19 mm) and 7/8" open-end wrenches with total length not exceeding 6.5 inches to remove the injector line nuts from the ends of the rail. Get a small (about 5.5 inches long) "lady foot" rocker style pry bar to pull up the injector. (Make sure the nut and connector tube are out of the way so you won't nick the end of the connector tube.) A 3/4" or 19 mm flare nut crow's foot and flex head ratchet will help remove the #5 and #6 injector line nuts. You also will want a 15/16" or 24 mm socket and flex head ratchet to remove the nuts at the cylinder head. A 3/8" drive socket cut down to 1 inch long gives better access for #3 and #6 connector tube nuts. In this engine, the injection line nut threads into the connector tube which is held in place by another nut that is threaded into the head.

Make up a steel or aluminum tube with an inside diameter of 1.15" to 1.25" and length of about 2.8" to press the new injector into its well. You may need to file it flat on one side if it is a thick walled tube, to clear the intake rocker. You don't want any stress on the electrical studs or plastic end of the injector. Greasing the injector body O-ring helps a lot for pressing the injector into its well in the head. To vacuum out fuel from a cylinder, I use a piece of clear, flexible plastic ("Tygon" or vinyl) 0.25 inch outside diameter tubing, about 3.5 to 4 feet long with a 9 inch long piece of 3/16" brake line pushed into one end for about one inch. The ends of the brake line should be chamfered and the tube cleaned of any metal shavings. You will insert the 3/16" steel tube into the cylinder through the injector hole to suck out any fuel that drained into the cylinder and

is in the piston bowl. The extra length of the plastic tubing allows a "belly" to form and trap the fuel that is withdrawn. If you prefer, it is safer to have a suction pump and trap attached.

#### **Procedures:**

First, remove the plastic cover over the engine and the breather assembly from the top of the valve cover (four bolts with 10 mm head and O-rings under the heads on 2003-2004 engines). Remove the valve cover lid (six bolts with 10 mm heads). You will remove the air intake for better access to the injector lines. It is held on with four bolts having 10 mm heads, plus one for the dipstick tube, and a 7/16" (11 mm) nut on the band clamp.

When removing the aluminum air intake horn from the head, it is easy to tear the gasket. Keep a couple of them around. Get Cummins part number 3969988 (the newest heat resistant type, replacing the 3938158 pink gasket that Cummins used in the past few years).

Plug the plenum hole in the head and the boost pipe so nothing falls into them. Be sure the areas around the lines at the rail and at the head are very clean. Remove the injector lines. Be sure to use a backup wrench on the nut at the head and on the ends of the rail to prevent damage to either the connector inside the head or the fuel rail. Keep the injector lines and exhaust rockers in order for correct re-installation, if you elect to address all six injectors at once. On many engines, the last digit of the injector line part numbers, etched on the engine end's nuts, are in numerical order from #1-#6, for example 3957081, 3957082, 3957223, 3957084, 3957085, 3957146. Remove the nuts at the head and gently pull out the connector tubes about 1/2" with an M14 x 1.5 thread nut and a screwdriver on the nut. The tubes have balls peened onto their outsides to index them in the head.

Remove the exhaust rocker arms assemblies. A rocker assembly is shown but you will usually only remove the exhaust rocker. Disconnect the solenoid wires at the top of each injector. Be gentle! These studs are easily broken. Remove the two injector hold down bolts (M6 x 1.0 thread, 8 mm or 5/16" head). Pull the injectors gently with the "lady foot" puller.



**72i21** Rocker assembly for one cylinder. Exhaust, pedestal, intake, rocker pivot shaft and bolt, and two bridges below to couple pairs of intake or exhaust valves.



**72i22** Common-rail engine with the "lady foot" injector puller positioned to lift #1 injector. (The exhaust rocker, injection line and connecting tube were removed first.)

If the intake valves were open, it may be necessary to loosen the intake rocker to get clearance to remove the injector. Listen carefully. If you hear fuel drain into the cylinder, you must vacuum it out with a hose through the injector tip hole in the head, as a piston bowl full of fuel will cause a hydraulic "lock" when you try to turn over the engine later. It is common to get two or three milliliters of fuel into a cylinder's piston bowl when removing an injector. I use the tube described above in the "tools" paragraph and gentle mouth suction, letting the fuel settle into a "belly" in the hose—no one wants or should get a mouthful of fuel! Check the injector well in the head and if the sealing surface at the bottom of the well is contaminated, mop it clean with a Q-tip that is held tightly in the partly flattened end of a tube to gain the needed length (I use an old 5/16" hollow engine pushrod).

Clean the injector wells so that there is no grit at the sealing surface on the bottoms of them. HPCR injector wells stay clean except for engine oil and deposits from the injector tips as they are pulled up through their holes upon removal. If there are heavy deposits making it difficult to install the new injectors, you can run a rifle bore brush through the holes into the cylinders to clean out the

passages the injector tips go through. Wipe out the sealing areas where the copper washers rest on the bottom of the wells, with Q-tips. You can use a hollow 5/16" automobile pushrod that is partially squashed near the end to retain one end of the Q-tip so it can't fall into the cylinder. The sealing ball area of the injector lines can get dirty or corroded, and subsequently leak. Usually cleaning with fine aluminum oxide or emery paper (600 or 800 grit) will take care of it. Be sure to spray off the area so no grit remains on the surface or inside the line. Don't torque the line nut over 25-30 ft lb; put a little grease on the threads and back side of the sealing ball where the nut grips it, to get a smooth torque reading and to prevent the line from twisting.

Grease the O-ring on the body of each new injector. Push the injector into its well using the 2.8" long tube over the injector body, bearing against the hold down bracket that is captive on the injector body. The factory service manual specifies that you snug down the injector hold down bolts, then relieve the tension and tighten the connector tube nut to 11 ft-lb. Then, tighten the injector hold down bolts to 89 in-lb and tighten the connector tube nut to 37 ft-lb torque. I suggest using a thin film of grease on the threads and sealing surface of the nuts. I also put a bit of engine oil around the hole in the side of the injector where the connecting tube fits. Install the exhaust rocker, and set the lash. The lash generally does not change with this procedure, but if your engine has a lot of miles on it, you might want to set the valve lash on all valves. Valve lash specifications for the 2003-up common-rail engine are as follows:

| Intake                    | Exhaust                   |
|---------------------------|---------------------------|
| 0.006 inch minimum        | 0.015 inch minimum        |
| 0.015 inch maximum        | 0.030 inch maximum        |
| 0.010 inch when resetting | 0.020 inch when resetting |

I prefer to keep lash measurements as close as practical to the same in all cylinders, and generally use 0.010 inch on the intakes and 0.020 on the exhausts on 12- and 24-valve engine types.

Re-assembly goes in the reserve order of the removal procedures above. Torque specifications for re-assembly are as follows:

**Injector Hold Down Bolt:** 8mm (or 5/16") head, 89 in-lb maximum; 80 in-lb may be "safer" if the bolts seem to be "stretching" excessively.

**Injector Wire Nut:** 8mm head, 11 in-lb. That's a very light torque—the M4 x 0.7 studs are easily broken; gently snug is another way to describe it. You can use a nut driver (like a screwdriver) to help you get a good feel when snugging down these nuts). Note that the yellow or brown wire is closest to the intake side or intake rocker.

**Rocker:** 10mm head, 27 ft-lb

**Connector Tube Nut:** 24mm or 15/16", 37 ft-lb

**Injection Lines:** 19mm or 3/4", 22 ft-lb

**Valve Cover and Miscellaneous:** M8 x 1.25 thread bolts with 10mm head, 18 ft-lb

**Joe Donnelly**  
TDR Writer

# Vibration Dampers

ISSUE 73

## IT'S TIME TO INSPECT YOUR HARMONIC DAMPER (But please don't call it a balancer)

by David Magnoli

As my truck nears the 90,000 mile mark, I thought I would take a look at the owner's manual to see what the recommended maintenance was for that milestone just in case I were to forget, or was unaware of, some suggested repair. I always read the manual when I buy a vehicle, but often forget how much useful information is in it. Under the 90K schedule was the recommendation of "Inspect Damper". I also noticed that this same prompt was listed at 30K and 60K. My first thought was that this referred to the steering damper (4x4). Not entirely sure, I looked it up in my service manual and found that it was not steering-related at all but was instead pointing me to that often overlooked, and for the most part, forgotten item more properly called the harmonic damper that sits on the front end of the engine's crankshaft directly in front of, and part of, the serpentine-belt pulley. Like a lot of people, I suppose, I never paid much attention to this black doughnut, and did not realize that it required any sort of inspection or maintenance. It does in fact deserve our attention and in the process of doing so, I learned quite a bit about this important piece of our Mighty Cummins Diesel engine.



The 5.9 stock damper uses a rubber ring between the cast hub and the machined-steel pulley/inertia ring to dampen the firing impulses of the Cummins engine. This picture clearly shows the degradation of this rubber, as well as the section that is missing, which caused it to wobble on Cliff Scott's engine. This should motivate the reader to inspect this important, but often-overlooked part, and make sure there are no signs of failure on your own truck. Surprisingly, the index marks are still in alignment on this damper but this one should have been replaced some time ago.

## What Is a Damper and What Does It Do?

Although often referred to as the harmonic balancer, because our Cummins is internally balanced (the crankshaft itself being balanced), the damper on our engines does not balance the engine. It damps harmonic vibrations and, as such, is a harmonic damper. Other diesel pickup engines are externally balanced and in addition to the damper, have a counter-weight either made as part of the damper, or bolted on in addition to it to provide the balancing requirement.

With each firing of the fuel/air charge in the cylinder, there is a violent but short-duration deformation or twist of the crankshaft as the force of the power stroke drives the crank against the resistance of the driveline. This occurs with each ignition event and results in the repeated twist and untwist of the crankshaft as this force alternately begins and ends, momentarily forcing the crank past its normal rotation, and then allowing the crank to rebound after each firing. This spring effect is more pronounced in a straight-six engine with its longer crankshaft than with the shorter crankshaft of a V configuration. It is also more pronounced at the front end of the crankshaft where there is less rotational resistance than at the transmission end. While the torque-converter or clutch/flywheel will offer minimal vibration damping at the rear of the engine due to their mass, they do nothing for the front end of the crankshaft, which will experience a greater degree of twist/rebound under power. This is also more of an issue in modified high-power engines with higher cylinder pressures and the associated higher crank torque-spikes. Varying with the speed and load of the engine, these firing impulses and rebound forces can, and do, set up harmonic and torsional vibrations in the crankshaft. And because it is the front of the crankshaft that drives the injector pump as well as the camshaft, increased vibrations and harmonic twisting can negatively affect their function as well.

Our engine cranks have a natural resonance inherent to their design, which means that they tend to vibrate much more at certain specific frequencies than others. When the power pulses are in phase with this natural tendency to vibrate, this will result in lost horsepower, increased bearing wear, unstable valve and injector-pump operation as well as the effects being felt in the vehicle. Harmonics are the frequencies that are smaller, less pronounced multiples of the primary resonance.

Everything has a natural resonance at which it will vibrate. Think of a piano with its many strings. The long and thick strings will vibrate slowly. Short and thinner wires will vibrate faster and, because they are connected to a soundboard, they allow you to hear these vibrations as sound. Hit a 2x4 with a hammer and it will vibrate also at a fixed frequency determined by its size, mass, and physical shape. You can try this experiment to better understand the principles of native frequency and vibration. The next time you are

standing on a single-span pedestrian bridge, such as one spanning a creek, stand in the middle of it and bounce up and down. You will feel its natural frequency as it shakes. If you time your bounces just right, and in cadence with and emphasizing this natural frequency, you can get the bridge moving up and down a surprising amount, much more so than if you were just walking across it. I am always astonished at how violently the bridge will shudder up and down if I continue this motion at just the right timing. Now imagine that in the center of this bouncing bridge you also have a 55-gallon drum filled with heavy gear-oil. Inside the drum and hanging suspended on a spring is a large, heavy steel washer that is allowed to move independently of the drum, which moves with the bridge. Now when you bounce on the bridge your motion is countered and dampened by the resistance of the weight moving against the oil. This is precisely what the engine damper on our truck is designed to do. The damper takes these short-duration shocks and absorbs them, thereby reducing the transmitted vibrations. The result is not only less stress and wear but also more usable power and a more stable valve train operation.



The pulley side of the stock damper shows the bonded rubber ring squeezing out from the gap between the hub and the inertia ring. The Service Manual clearly states that any protrusion beyond the face of the ring other than a slight convexity requires the replacement of the damper, as this indicates the beginning of the failure of the rubber. Although there are no missing sections on this side of the damper, the fact that the ring is so far out of the gap indicates a failure of the damper.

### The Stock Damper

The stock 5.9 damper, in good working condition, for the most part works well with the stock engine it was designed for. But when we add power and increase these internal forces, or as it ages, the stock damper may not be up to the task anymore. The engineers that design the stock damper do so with our engines' stock horsepower and native frequency (RPM, crank weight, and load) in mind and try to design the damper to be effective at the most offending part of the power band by using a tuned damper designed to address a certain range of vibrations. The harmonic damper bolts to the front flange of the crankshaft and is built as part of the serpentine-belt pulley that drives the A/C, water pump

alternator, and steering pump. There is a difference, however, in how this damper works on 5.9 and 6.7 engines. On the 5.9 engines there is a cast-iron hub which bolts to the engine crankshaft. The serpentine pulley is not part of this hub, but is machined as part of the heavy, outer steel inertia ring. Between this hub and the pulley/inertia ring is a layer of rubber that separates the two and is bonded to both. It is this tuned-rubber ring that allows the damper to work by allowing the two parts to flex and move independently of each other, damping out the firing impulses and converting this energy to heat. The stiffness and thickness of this rubber ring is designed to cancel out a specific frequency of vibration, determined by fueling, RPM, engine load, etc. and is limited to a very narrow band of resonance, that which the engineers have decided is needed. Due to engine heat, age, and continuous flexing, this rubber will deteriorate over time, becoming less effective. Because the pulley is being driven by rubber, as opposed to being part of the hub itself, when the damper deteriorates, it also affects the alignment of the pulley to the belt.

Starting in 2007.5 with the 6.7 engines Cummins changed the damper design, foregoing the rubber in favor of a viscous-damped type. This damper works by enclosing an inertia ring inside a housing that contains a thick silicone fluid. This allows the damper to be more effective at a much wider RPM range than the tuned-rubber type used on the earlier trucks. Because the inertia ring is now floating in a thick viscous fluid rather than being a bonded mechanical connection, it offers a variable resistance to the firing impulses and therefore is better suited to countering them and canceling vibrations. I'll talk more about this type when discussing the aftermarket dampers. These newer dampers do not require any periodic inspection, so the rest of this article applies primarily to 5.9-liter equipped trucks.



This shows the stock damper in good usable condition. Notice the rubber ring compared to the previous picture, and how it is flush with the hub and inertia ring.

The two holes at the bottom of the picture on the damper were drilled when the damper was balanced. This damper is off of my 2001 with less than 90K miles and has seen much less severe use than the other damper, which has seen many high-powered miles towing more than 13,000 pounds.

## The Need for Inspection and Replacement

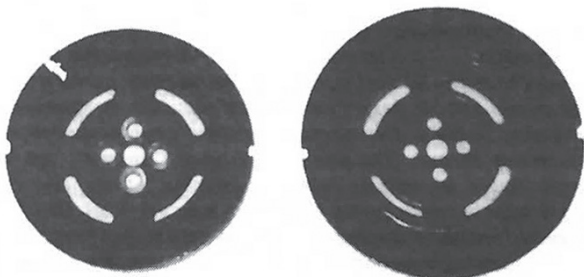
An index mark on the 5.9 dampers, in the form of an inscribed line, crosses both the pulley hub and the pulley/inertia ring so that you can see if there is any degradation of the damper, requiring its replacement. The service manual for my truck (2001) states that if this index line is more than 1/16" out of rotational alignment, the damper should be replaced. Another requirement for replacement is the migration of the rubber ring in a lateral direction, causing it to move out past the face of the inertia ring. This clearly indicates that the damper on our trucks is something that wears out over time and will need to be replaced at some point. The following story will show that this part is something that should be inspected as directed by the Owner's Manual.

A few days before leaving to attend this year's annual TDR May Madness event held in Pahrump, Nevada, longtime TDR member Cliff Scott was giving his 2001 truck an inspection when he noticed that the damper was wobbling when the engine was running. Upon closer inspection, Cliff noticed that not only was the inertia ring out of alignment with the hub, but there was a substantial amount of the rubber ring actually missing, as well as squeezing out of the space between the two. It is his damper I used in the previous photos.

He has close to 180K miles on his 2001 but the amount of damage tells me that this has been going on for some time, proving that the Owner's Manual inspection recommendation should be wisely followed. Luckily for Cliff, I had a brand new Fluidampr sitting on my bench in preparation for this article and I offered it to him to use. He was able to install it and drove over 450 miles to Pahrump towing his fifth-wheel. He liked it so much I had to order another one and hope it would come in time for my review.

While I have heard stories of stock tuned dampers coming off of the hub, and have seen the bolts broken or missing, as well as the cast hub cracked, I would hope that the driver would feel increased vibrations indicating that something was amiss before that would occur. However, the possibility for such failures does exist. If the failure proceeds slowly, the driver may not notice the increase in vibrations. The point here is not intended to alarm anyone though; it is simply to remind you to "Inspect Damper," which should include checking the torque (92 ft-lbs) on the four mounting bolts.

Even if your stock damper is not damaged, if you have substantially increased the power of your engine, your stock damper will most likely be out of its designed range. There was a substantial size difference between the 160 and the 215 horsepower dampers on the 12-valve engines, indicating that more power requires an increased level of damping. You can see this difference that was noted in TDR 18, page 23.



This is a reproduction of a marginal photo. The key item; yes, there is a size difference between the dampers. 160 on left, 215 on right.

## Replacement Choices

When faced with the replacement of the harmonic damper you have several choices. You can use an OEM unit from the dealer, for which my local Dodge dealer quoted me \$420 before tax. It was only \$201.47 before tax directly from Cummins. You also have a couple of aftermarket choices.

There are a few companies making what are essentially the stock-style dampers, but if you want an improvement over stock, there are really only two choices that offer a high-performance model. Both of the following aftermarket dampers have what I feel is a definite advantage over the stock damper besides just better performance. The serpentine belt pulley is machined as part of the hub, and as such is driven directly by the engine, not by the transfer of power through rubber as in the stock design. This means that the pulley cannot become misaligned, even if the damping function were to fail or lessen in effectiveness. Nothing will ever be thrown off the crank from deterioration of a rubber part. Keep in mind that the prices I used below are list prices, street pricing is considerably less. Also, prices shown are for my 2001; other year models may vary slightly.



The ATI Super Damper is supplied in three parts: the damper itself, the vehicle-specific hub, and the aluminum pulley. All necessary bolts and screws are supplied to assemble this damper, but it cannot be assembled before installation on the engine, due to the fact that the installation bolts do not fit through the crankshaft flange holes after it is assembled. It requires that the pulley and hub be bolted to the crank flange first, and then the damper ring is installed with the six Torx-Plus screws and six, 12-point cap bolts. Loctite 242 must be used and the torque values (printed on the damper label) must be followed.

## ATI Super Damper

The first option is the made-in-USA, ATI Super Damper at \$475 list, which uses eight elastomer O-rings on a grooved, floating inertia ring housed inside an inner and outer shell that are pressed together and then bolted onto a vehicle-specific steel hub. There are three O-rings on the inside radius of the inertia ring as well as three on the outside. These contact the inner and outer surfaces of the two shells. The other two O-rings on the inertia ring contact the inside faces of the two shells. Each of these rings is made of varying density (durometer) designed to come into play at different RPM to manage variable harmonic vibrations. These dampers can be tuned for a specific application by varying the density of each of the elastomer O-rings. The Cummins version is larger and heavier than other applications, with the larger number of elastomer rings tuned to our engines. There is an important difference between this damper and the stock rubber-mounted one in that the O-rings offer a sliding surface rather than a bonded connection that is dependent upon the flex and rebound of the material. The inertia ring in the ATI is free-floating within the housing, allowing it to move and better absorb variable harmonics. When used in applications up to 800hp, they are rated to last 10 years and can be rebuilt by ATI, or by the user if you buy their kit, simply by taking the unit apart and replacing the rings.

They also exceed SFI 18.1 specifications. The hub directly drives the pulley, eliminating any chance of belt alignment issues.

The ATI arrives unassembled in three parts: the inertia ring, the vehicle-specific hub, and the aluminum pulley, each of which is zero-balanced to two-tenths of a gram. There is a dimple on the hub and ring which must be aligned. This damper must be installed on the engine in the following order, the pulley and hub first, and then the damper ring itself with the 12 supplied bolts and screws. This is because the washer-head crank flange bolts will not fit through the mounting holes after the damper ring is placed on the hub. New, longer crank-flange installation bolts are also supplied with the ATI because of the thicker hub. The stock bolts will not work with the Super Damper.



The Fluidampr is a one-piece laser-welded assembly that is ready to install on your engine crankshaft. It is sealed and requires no maintenance. It is all steel and after coating the center-bore with anti-seize, installs in one piece. You will need to reuse your stock installation bolts or buy new ones, as none are supplied with this damper. The bolts are torqued to 92 ft-lbs.

## Fluidampr

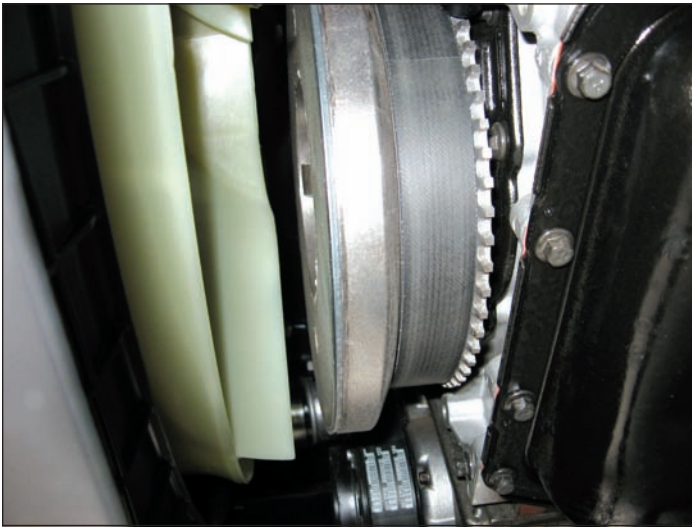
The second option is a Fluidampr at \$436. This USA-made, all-steel product is supplied completely assembled and ready to install. This damper is made in six Cummins models, with the size, weight and characteristics designed specifically for each model/year of Cummins engines; it is not a one-size-fits-all. Dodge/Cummins changed to this type of viscous damper with the introduction of the 6.7 engine. It uses a steel inertia ring fitted inside a steel housing with a clearance gap that is filled with a thick silicone fluid, allowing it to float and mask vibrations over a much larger range of RPM than the stock, bonded type. Because it is insensitive to any specific frequency, it is able to self-tune to whatever vibration input it is exposed to. It is sealed and cannot be opened, and is maintenance-free for the life of the damper, which by design should never wear out. The machined, nylon-coated inertia ring is precision-balanced both before and after the coating process, and the balanced housing is laser-welded. The machined-steel serpentine-belt pulley is part of the hub and housing. The Fluidampr is also available for the 6.7-liter engines and includes the tone ring as part of the damper. The Fluidampr viscous design has been around since 1946 and also meets SFI 18.1 specifications. On any year truck, Fluidampr recommends the use of their available Cummins pinning kit to pin the damper to the crank flange if RPM are to exceed 3500. The kit is supplied with a drilling fixture, bit, and two hardened roll pins.



On the left is the Fluidampr, larger in diameter and thicker than stock, and the heaviest of the three at 24 pounds. Next is the stock damper weighing in at 14 pounds, followed by the ATI Super Damper at 18 pounds. The ATI is smaller in diameter than the other two and also uses an aluminum pulley, unlike the steel used on the Fluidampr and the stock damper. The pulley diameter remains the same on all three units, keeping accessories spinning at designed speeds.

## The 6.7 Damper

Another possible choice for replacing the tuned rubber style 5.9 damper is by using the 6.7 damper on a 5.9 engine. There has been talk of this on the TDR forums as well as other diesel forums, but I have not seen anyone actually do it yet. The fluid-type damper on the 6.7 engines is a dramatic improvement over the 5.9 design but it is not a direct bolt-on replacement. At the time of writing this article, I called Cummins West and my local Dodge dealer to see if they had one of the 6.7 dampers in stock and was told that neither they, nor the factory, had any available at that time. Being rather new, they are not at the point of failing yet, and there does not seem to be much call for them. There seems to be a clearance issue with the newer design on a 5.9 between the damper and the fan pulley, but I have not been able to get my hands on one to verify this. If these issues can be easily resolved, this may be another option for better performance.



**The 2011 6.7 Cummins engine uses a harmonic damper that is of the viscous-fluid type. This change from the tuned-rubber was made with the introduction of the 6.7 engine in 2007.5. The tone ring is part of the pulley on this damper.**

### Enough Talk Already, Do They Really Work?

So far the claims of the aftermarket manufacturers sound great, but I wanted to see for myself if they were valid. I put the Fluidampr and the ATI Super Damper through their paces by installing them on my 2001 Cummins to see how they would perform under various driving conditions in comparison to the stock damper.

The first thing you will notice about these dampers is the weight. Mass is critical to being effective. A small, lightweight damper will not do much regardless of what method it uses to quell the vibrations, which work against this mass. You need the weight to counter the input energy. My stock damper weighs 14 pounds. The ATI tipped the scales at 18 pounds, a 4 pound increase over stock. The Fluidampr weighed-in at 24 pounds, a full 10 pounds heavier than the stock unit. Aftermarket dampers for First, Third, and Fourth-generation trucks vary slightly in weight from these, but all are substantially heavier than stock.



**The damper is hub-centric and is aligned on the extension that is machined on the end of the crank. It is important when installing whichever damper you use, to use anti-seize or grease on this hub when fitting the new damper so as not to gall this close-fitting surface when turning the hub for bolt alignment.**

### The Installation Process

The first step in the installation is to remove the belt. If your belt-routing diagram sticker is missing, draw the path or take a picture so you can re-install it properly. With an automatic transmission the engine turns as you remove the damper bolts, so I removed the small inspection plate under the torque-converter and used a pair of Vise-Grips on the flex-plate, cushioned with a piece of leather, and let it stop against the transmission housing. With a manual transmission just leave it in gear and set the parking brake. After removing the four 15 mm bolts that secure the damper, it is an easy removal, as it is not pressed onto the crankshaft. The dampers are hub-centric, having a close-fitting, center-bore that aligns with the machined snout on the end of the crankshaft flange. They are heavy though; be sure you get a good grip on it before removing that last bolt. After cleaning off the surface of the crank flange, and applying a little anti-seize compound around the center hole, I torqued the bolts to 92 ft-lbs as listed in the Service Manual. I used blue Loctite on these bolts, although there was none from the factory. I've read on the TDR forum that these bolts should not be reused as they are said to be torque-to-yield, but the Service Manual does not say anything about using new bolts. Obviously if they are damaged they should be replaced. Because I had torqued mine several times during the testing procedure, going back and forth between the different dampers, I replaced them with new bolts with the final installation. With the number of TDR forum posts about broken bolts, I would suggest that new bolts would be cheap insurance.

The Cummins part number is 4937228 is for years '07-current. The Cummins part number 3903857 is for years '94-'06.



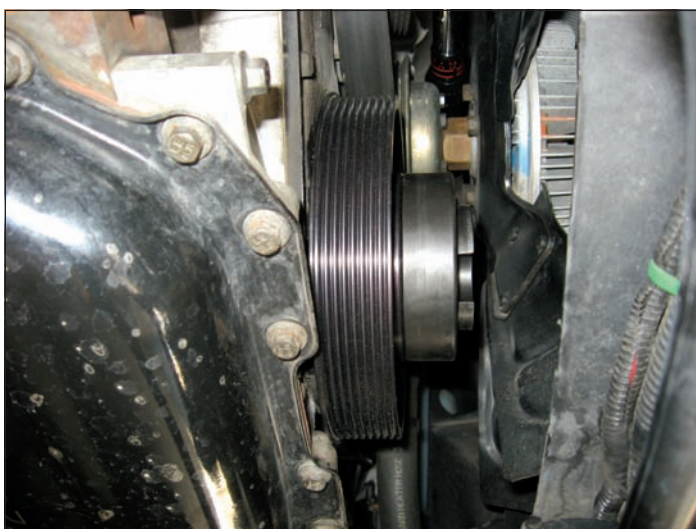
This shows the interference between the damper and the washer-head bolts on the ATI which requires this damper to be installed in separate steps. You can see the two bolts in the installed position, and the two that hang on the damper ring. After installing the hub and pulley on the engine, the damper ring is installed using the 12 supplied screws and bolts, using Loctite 242 and tightening to given specs.



The ATI Super Damper in position on the crankshaft. It is smaller in diameter than the stock unit but is thicker and weighs an additional 4 pounds. The timing marks are of no use on our Cummins engine, but are there because this inertia ring shell has other applications that require them. This damper is made specific to a Cummins.

You can read Scott Dalglish's article about changing a 12-valve damper in Issue 18, page 23. Also, in TDR Issue 52, page 28, there is a situation describing the alternator not charging due to the crank sensor not being in alignment with the timing notch on the damper. When installing on a 12-valve this is something to watch out for.

Installation of both the ATI and the Fluidampr on my Second Generation 24-valve truck ('98.5-'02) did not require the removal of the fan or the radiator shroud, although it is recommended in the instructions. I was able to do the removal, although it is a bit tight, just by removing the belt and unbolting it. You can rotate the fan blades to a wide spacing to allow easier access.



The ATI requires that you install the pulley and the hub to the crank first, and then the inertia ring can be mounted to the hub. It is a bit more difficult to do this with the fan shroud in place, but with a little patience it can be done.

First and Second Generation 12-valve truck (1992-1998) installation is fairly straightforward. There is plenty of clearance to unbolt the old damper and install the new one after removing the belt. With the larger diameter of the Fluidampr, you will have to relocate and rewire the magnetic tach pickup from the top of the crank to the side and then adjust the clearance gap to the pickup, which is best measured before removal. The needed parts and instructions are included with the damper.



The Fluidampr is one-half inch larger in diameter than the stock damper and weighs a full 10 pounds more. Along with this, it is also thicker than stock, but it has plenty of clearance once installed. Leaving the fan and shroud on was a bit of a knuckle-buster on my truck (2001), and other year models may require their removal.

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Third Generation 5.9 trucks ('03-'07.5) and the 6.7 ('07.5-'09) have a slightly different installation due to the closer clearances. Again, the instructions state that the fan and shroud need to be removed, and although it does make it easier, I have seen it done on a '04 without doing so. **(Editor's note: We also installed a Fluidampr on a Third Generation truck, a '03 model, without removing the fan.)** However, the serpentine belt must be routed between the damper and the water-pump pulley before the Fluidampr is installed because of closer clearances with its larger diameter. This also means that to change the belt you must loosen or remove it also. This is not an issue with the ATI, due to its smaller diameter.

Installation was easier since the Fluidampr is one piece, but that was only because I chose not to remove the fan and shroud. And because most of you will not be installing these four times in one day it will not really be an issue

### Road Test Results

After installing each of these dampers I took the truck out for a test-drive to see if I could tell any difference between them and the stock unit. Keep in mind that this is not by any means scientific, but rather a seat-of-the-pants evaluation of these products. I don't have the instruments to measure or record actual differences, only my impressions. I drove the truck all on the same day, changing dampers and going back over the same route for comparison. The truck was at operating temperature for each of the tests. I drove the truck with the various dampers as follows: stock, ATI, Fluidampr, and then stock again just to get a good feel for any differences. I drove for about an hour with each one installed and tried to cover many types of driving, from freeway to winding steep roads to stop and go traffic and was surprised to actually feel a significant difference.

### Idle Quality

My truck does not have large injectors that cause a pronounced idle lobe like some trucks do. The ECM (engine control module) does not have to work very hard to maintain idle speed. But there is always that slight throb at idle when in gear that disappeared with the ATI and Fluidampr installed. The truck is dead-still at idle. This was confirmed when I re-installed the stock damper and could feel the throb return.

Manual-equipped trucks are said to have less gear clatter and to be smoother at idle with the installation of better dampers. I would think that a torque-converter, being a fluid-coupled device, would tend to be superior at absorbing vibrations at the rear of the engine than a clutch would, and would explain why manual transmission drivers would see a more dramatic idling improvement. Many claim reduced noise from the clutch. Also, with the installation of the damper on my friend Cliff Scott's truck, he noted that the truck was easier to shift into reverse.

### Let's Drive It

At slow around-town speeds, there is nothing noticeably different about the aftermarket dampers, as the truck is not under much load under these conditions. Moving repeatedly from a stop did seem smoother with the two aftermarket models.

The real differences are noticed when driving under increased load. Under hard acceleration there is a reduction in the vibrations with the ATI and Fluidampr over stock. The engine just feels smoother. On a long incline with my truck in overdrive going 50mph, I'm only spinning around 1400rpm with my 3.55 gears and the engine is almost lugging. Accelerating hard to 2000rpm repeatedly resulted in much less of the shuddering I am used to when driving on this road. The vibrations in the steering wheel and pedal were greatly reduced under the increased engine loading.

Another area where I experienced a noticeable difference was at higher rpm. Accelerating in third from below 2000 to 3000 usually caused a dramatic increase in vibrations as the truck accelerated. This is also felt in the steering and the go-pedal. This has always been more noticeable with my Edge box turned up. With each of the aftermarket designs there was again a smoother overall feel under these higher power levels on the same stretch of road.

As far as any differences between the Fluidampr and the ATI, it was hard for me to determine. I would give a slight edge to the Fluidampr at idle and lower rpm, possibly due to the increased weight over the ATI. But, at speed and under load, I could not tell any real difference, as both were so much better than the stock damper. The other thing to consider is that although I could definitely feel an improvement in performance under several conditions, this is a part that does its job protecting the engine even if you can't feel it. A harmonic damper is not something that is designed or installed for the comfort of the driver; that is only a side benefit of it doing its job. In other words, it is designed to do a specific task. If you can feel the difference, great, but that is not the true test of its performance or protection. The fact is that the harmonic damper is protecting the engine, whether you can feel it working or not. Harmonic and torsional vibrations are very much an issue in our diesel engines, especially when power is increased, or when towing heavy; and, as mentioned before, the stock damper with its limited range of function only narrowly addresses this.

### Conclusion

If your truck is stock, and your damper is in good condition, you probably do not need a better performing alternative although they are certainly a noticeable improvement. If however, you have substantially increased the power of your engine, I believe that you will benefit from the increased damping available from the aftermarket designs.

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The problem that I see with a stock-design 5.9 damper, and the reason that I feel the aftermarket designs are so much better, is that it really does not absorb the vibration as much as just delay it, or throw it out of phase slightly. This, along with the fact that the bonded rubber ring only allows a limited range of damping, contributes to the stock damper doing merely part of the job assigned to it. Increased horsepower places more demands on our engines, and add to that the fact that the stock dampers do eventually wear out, and you have the need for an improved vibration-damping solution.

The ATI and the Fluidampr actually absorb the vibrations resulting in a smoother and more effective damping of the engine's resonance. Each of these designs allows the heavier internal inertia ring to float and move within the housing at a changeable amount dependent upon the varying inputs from the crankshaft. This allows them to self-tune to the variable inputs. They don't store any energy like the stock one does.

The ATI and Fluidampr are not only able to absorb more, but they also do it at a wider range of resonances, damping out the second, third, (and so on) order harmonics generated under increased engine loading. Being much heavier than stock means that there is more mass that the crank impulses have to work against and overcome, resulting in improved damping action. Another advantage is the fact that the pulley is part of the hub and not driven by a rubber ring, ensuring that the belt will always run true.

If your damper has failed and you are looking for a replacement, I would strongly consider the aftermarket type. If you are the kind of guy that just wants the best performance and you don't mind paying for it, you can replace your damper even if it does not show any signs of deterioration. Although that might seem wasteful, we tend to do exactly that with all the other parts of our trucks, often resulting in quite a few usable parts stacking up in our garages. Such is the diesel addiction. Although I was skeptical about the real-world advantages of these products, after my research and a direct comparison, I can clearly see the limitations of the stock units due to design and longevity issues and can very much feel the results of better damping. The two reviewed products have been around for a long time and have many miles of racing experience with high-rpm and rough usage. The quality, tolerances, and finish of both are excellent. They are not inexpensive, but their effectiveness is well-proven. They work and your engine will thank you.

**David Magnoli**  
TDR Writer

#### **Sources:**

##### **ATI Performance Products**

6747 Whitestone Road  
Baltimore, MD 21207  
(410) 298-4343  
[www.atiracing.com](http://www.atiracing.com)

##### **Fluidampr by Horschel Motorsports**

180 Zoar Valley Road  
Springville, NY 14141  
(716) 592-1000  
[www.fluidampr.com](http://www.fluidampr.com)

# Fuel Tanks

ISSUE 75

## OPTIONS FOR AUXILIARY FUEL TANKS, OR HOW TO GET WELL-TANKED

by David Magnoli

There is no end to the number of products on the market claiming dramatic fuel savings with their purchase and use. Everything from electronic devices, hydrogen generators, fuel line magnets, magic potions, aerodynamic additions and so forth are offered with some pretty proud claims and promises of substantial improvements in your fuel economy. And although personal driving habits continue to be the biggest factor in fuel savings, I can personally attest to the fact that by changing injectors, advancing timing, decreasing exhaust back-pressure or intake restriction, and other similarly efficient modifications, noticeable increases are certainly to be had with our diesel engines. But if you really want more driving range while towing, hauling, or just tooling around in your Turbo Diesel, any small benefit from any of the above just won't do it. Leave all the false claims behind, and just add more fuel in the form of an auxiliary fuel tank.

There are several good reasons and benefits for adding fuel storage capacity to our trucks. I've carried a few five-gallon cans of fuel on longer trips enough times to know that there has to be an easier way. I got tired of dripping fuel down the side of my truck while balancing forty pounds of sloshing diesel. Along with the simple fact that having more than stock capacity allows a greater range, having the room for more fuel allows you to buy fuel less often and when you want to, as opposed to when you have to. With larger aftermarket tanks you are not as often at the mercy of the higher fuel prices so regularly seen at some off-the-beaten-path fueling stations or states when traveling, allowing you to drive on to more reasonable rates. Especially when towing, or with a heavy slide-in camper perched in the bed of the truck, we sometimes end up places where fuel availability is limited and is priced accordingly, or it is quite a distance between stations. Having to pay a lot more for fuel than you would have to in a more ideally located area should be enough of an incentive to consider the luxury of one of the many aftermarket fuel tank possibilities. Or, if you are like me, and you desire something a little different, you can design and build your own custom system, which I'll share with you later in the article.

## THE LEGALITY OF IT ALL

At some point it is wise to consider the legality of carrying all that extra fuel around in your truck. Does anyone even care? As a matter of fact someone does care: the Department of Transportation, (Federal Motor Carrier Safety Administration) the EPA, and in California, the CARB (California Air Resources Board), and they have rules and regulations that apply to how much and in which manner you may drive with all that extra fuel, as well as the system that allows you to transfer the fuel to your stock tank from an in-bed model, whether it be a gravity-feed or a pumped system. Diesel fuel, considered a non-flammable fuel, does not have the same restrictions as gasoline in many cases. This article addresses only diesel fuel tanks. There are specific requirements regarding the construction of the tank, such as the method of welding seams, filled capacity percentage, types of fittings, the thread type on fittings and drains, as well as venting and mounting location. (Example: DOT regulations prohibit any fuel tank that is located forward of the front axle of a powered vehicle.) Fuel lines, and selector valves also have requirements for their location, use, and protection. CARB rules have more to do with spillage and evaporation, which falls under the Clean Air Act and concerns air quality and environmental issues. The full details are found in sections 393.65-393.69 of Subpart E-Fuel Systems, of the Federal Motor Carrier Safety Administration.

The popular suppliers of aftermarket tanks must comply with all the regulations during the manufacturing process, including drop testing, pressure and leak testing, vent, drain, and filler locations and structural integrity, as well as providing the appropriate markings on the tank showing the makers' name, manufactured date, capacity, approved fuels, and what section of the regulations it conforms to. Basic common sense would dictate that any fuel spilled during the filling of an auxiliary tank should not fall onto any part of the exhaust or electrical systems, and no part of the tank should extend outside the body of the vehicle. Nor should there be any fuel filler located inside the passenger compartment. These are some of the many issues that are addressed in the DOT regulations. There are slightly differing rules that apply to vehicles over or under 10,000 GVW. Buying a system from a reputable manufacturer will ensure that your auxiliary tank is in compliance with these rules.

## WHERE TO PUT THE TANK

When considering an auxiliary fuel storage tank there are only a limited number of locations where that extra fuel might go, and there are several options within these locations. The location you choose has a lot to do with how many additional gallons you wish to add. Besides portable fuel cans, the most obvious choice is to add capacity in the bed of the truck, and this is a popular choice, as there are many types and sizes that can be installed back there in the wide open spaces. Of course those wide-open spaces only exist if you don't haul a camper, welders, motorcycles, hay, camping gear or any other of the varied things we haul from one place to the next. If you can't spare the truck bed, then you are going to be interested in one of the stock-location replacement tanks that sit under the truck where your stock tank is now, but with up to 40 gallons in additional capacity, depending on the year and model of your truck. We will explore these different types in this article as well as the systems used to fill them and transfer that extra fuel into the main tank.



**This tank is a 54-gallon replacement tank that sits up under the truck in the stock location. It does hang lower than the original plastic tank, although still above the axle and differential, but it offers a larger amount of fuel without any fuel system modifications. Depending on truck year and model, these tanks offer up to 75 gallons total fuel without losing any in-bed space. With the increased weight of the steel tank as well as the additional fuel, the mounting straps on this tank are substantially stronger than the stock version.**



**By dropping the spare tire 6", this tank adds 30 gallons to the stock capacity. It is no longer offered by the manufacturer but could be custom-built if so desired. The tank is filled through an added fuel filler that is cut into the side of the truck bed behind the driver's rear tire. It is mounted very securely on the cross members and frame of the truck. This one has its own level sender that will show on the dash gauge.**

## STOCK REPLACEMENT TANKS

We are able to carry 35 gallons of fuel in our stock tanks, 34 if you own a short-bed or Mega-Cab truck, (22-30 if you drive a First-Gen). You can add 4-5 more gallons in the stock tank if you own a 2003 and newer by adding the tank-vent modification that moves the vent to the top of the tank. While that is a far cry better than the 20 gallon tanks that used to be the standard of many years ago, it is still not enough if you take long trips while towing heavy. By replacing the stock tank with an aftermarket version you are able to add up to 40 gallons of fuel, although most are around 52-56 gallons total, depending on the year and model of truck. These are available in either welded, aluminized-steel tanks, or in a molded cross-linked polyethylene, and are larger in size, utilizing the empty spaces under the truck. They also gain capacity by eliminating the rounded corners of the stock tank, increasing the area for fuel. They contain internal baffles (except for the plastic molded tanks) to minimize the movement of fuel back and forth inside, something the stock tanks do not have. Some available aftermarket tanks also use the area above the spare tire to increase the fuel volume, but these will result in the spare tire sitting 5-6 inches lower. These tanks either bolt up underneath the truck with similar mounting straps that the stock tank uses, or some bolt to the frame and/or cross members, depending on manufacturer preference. The fuel module containing the level sensor, pump (in some cases), pre-filter, vent, rollover valve etc. is swapped from your tank to the new one, and no modification of fuel supply or return lines, vent or filler is required. This also ensures that your stock fuel gauge reads as accurately as the stock tank even with the increase in capacity. A half-tank of fuel will still read one half-tank, but that amount will obviously be more than the lesser stock amount. The miles-to-empty calculation on the trip computer (if so equipped) however, will not be accurate with the larger tank. These tanks will also hang lower than stock, ending up slightly below the frame rails.

Joe Donnelly's article on the installation of a Third Generation stock-replacement tank in TDR Issue 48, pages 166-168 (available online, under Digital Magazines), gives a detailed look at what is involved in the process of swapping out the stock tank with one of the larger 56-gallon versions.

There is also a system available that along with the replacement tank that adds a second, connected tank installed above the spare tire, for a total capacity of up to 75 gallons. These rear tanks are no longer available separately like they used to be. They were at one time available as a 30-gallon add-on tank, filled through a separate filler installed into the side of the truck behind the rear wheel. In TDR Issue 46, page 141, Jerry Nielsen details the installation of the two-tank 60-gallon system.

If you take this route I would suggest saving the stock tank in the event that you sell the truck and want to transfer your aftermarket tank to the new one, assuming that it will fit.



**This fuel filler is still available to use in a camper shell or in the truck bed to allow the filling of an auxiliary tank. This one is mounted on a clean First-Gen truck and makes an easy job of filling the spare-tire located tank seen in the previous photo.**

## IN-BED TANKS

If you are able to use the in-bed tanks, then you have many more choices than you have with the stock-replacement type tanks, simply because you are not limited by the space restrictions that come with the under-truck conditions. In-bed tanks are offered with over 100 gallons of extra fuel. According to two aftermarket tank manufacturers I spoke with, Federal law states that no one tank can exceed 118 gallons, and you will see the maximum sizes available in the 98-103 range to stay within this requirement. My contact at DOT (NHSTA) however, told me that there was no limit to the total amount of diesel fuel that could be carried in a pickup truck rated at under 10K GVWR and made no mention of maximum tank size. At no more than 95% full as required by law (for expansion), this still gives a dramatic increase in extra fuel.

There are two types of in-bed fuel tanks and their name pretty much defines what they do. An auxiliary tank is one which is connected to the fuel system of the vehicle, just like the under-truck models. These tanks are able to supply fuel to the main tank automatically or manually, and are plumbed directly into the main fuel system. The other type, a transfer tank, is designed to carry fuel independently of the vehicle system and is used primarily for the transport of fuel for the refueling of, or the transfer of fuel to, other vehicles, such as construction equipment, generators, pumps, or any other stationary diesel-powered apparatus. Transfer tanks are equipped with a tank-mounted pump, either electric or manual along with a hose and nozzle to allow easy fueling. When you sell your truck, either type of these tanks is easy to remove and re-install in the next truck. In bed tanks are one of the few things we add that is not year or model-specific.



**The tank-toolbox combinations offer accessory as well as fuel storage in a compact unit. Even placed farther back in the bed to accommodate the exhaust stacks, this diamond-plate model still sits well ahead of the fifth-wheel hitch and is installed using the weld-on tabs to bolt to the truck bed for a secure installation.**

**These are available as either an auxiliary or transfer style. Tank-only versions are similar in size and shape but lack the storage option.**

## IN-BED AUXILIARY TANKS

If you just want fuel capacity in its simplest form, this type of tank is tough to beat. These tanks are available in capacities from as low as 18 gallons up to 100-plus gallons in either powder-coated, painted aluminized-steel, or aluminum diamond-plate. Mounted in the bed of the truck, they are connected to the main tank and are filled through a top or front-mounted fill neck usually on the driver's side. They will most often be supplied with a pickup tube, a vent (often with a rollover valve) and the fill neck. Many of these tanks will fit under a tonneau cover, not being above the level of the bed. In the larger sizes, even though they sit well ahead of fifth-wheel hitches, such a tank can block the driver's vision when backing up under a fifth-wheel or gooseneck hitch, making it hard to see what is going on. The remedy for this situation is one of the wedge or L-shaped tanks. With the narrower or sloping top visibility is restored but often at the cost of the tank being larger in depth. This type of tank typically has mounting tabs welded on that allow it to be bolted to the truck bed for a secure installation.



While the under-truck tanks will use the dash-mounted fuel gauge to show remaining fuel, the in-bed tanks typically have a fuel gauge installed to show the level. This one is under the lid of a tank/toolbox combination and gives an accurate indication of when it is time to refuel.

## IN-BED TANK-TOOLBOX COMBINATIONS

This is a handy design that is available in both auxiliary and transfer tank versions, and consists of a tank below a lockable, hinged-lid toolbox. Although not as roomy as a dedicated cross box, they offer a fair amount of room for tool and accessory storage that is readily accessible, along with fuel capacities similar to the tank-only versions. The transfer versions will have the fill neck, hose, pump, and nozzle usually exposed on the top or mounted in a lowered notch on the corner of the tank's exterior for use without opening the lid, while the auxiliary versions usually have these items contained within the lockable lid, offering more security. Some models have the fill neck in the front face of the tank as opposed to under the lid. When used as an auxiliary tank, the pickup and vent fittings will be located along the front or side of the tank, with a fuel-level gauge usually mounted under the lid. These options will of course vary by manufacturer. These combination tanks are available in a painted finish or in aluminum diamond-plate.

## IN-BED SADDLE TANKS

Saddle tanks are another option for carrying fuel in the bed of the truck. They fit into the area ahead and behind the wheel-wells and allow the full usable length of the bed to be retained, as well as the full width between the wheels. The plumbing is a bit more complicated due to the fact that you will have multiple fuel pickups if you use more than one of these tanks. And if you use a gravity-feed system, depending on how many tanks (up to four 11-gallon) you decide to use, this also means a few more holes in the bed to bring the fuel lines down under the truck to the main tank. Because the wheel wells will separate the tanks, this makes it more difficult to connect the low points of the tanks together.

## IN-BED TRANSFER TANKS

These tanks are for the specific purpose of transporting diesel fuel only. Many of these are prohibited from being connected to your fuel system and are only to be used as intended, although some models are convertible and can be used as auxiliary tanks also.

Most are rectangular or L-shaped and fill from the top. They are equipped with a reinforced 2" FTP coupling for the installation of a permanently-mounted electric or manual pump as well as a hose and nozzle. The electric pumps used with these tanks are special in that they are bypass pumps, meaning that when the nozzle is not open the pressure is bypassed within the pump. If you were to use a non-bypass pump and then close off the output while running, you might blow a fuel line off due to the increase in pressure with no place to go. When used only for off-highway applications these are quite often filled with red-dyed, non-highway fuel, which is not taxed the same as on-highway diesel. But this fuel should not be used if you operate your truck on the roads, as this carries a hefty fine if you are caught. Transfer tanks are usually painted white, as they are more utilitarian, but there are some available in aluminum diamond-plate also.



Most manufactured systems will use a Tee in the 3/4" vent line to supply fuel from the auxiliary tank to the main tank. This can also be used in a gravity-feed system. It makes an easily-installed connection that is also very accessible under the truck. This picture shows how I connected my supply, using a 3/4" brass Tee with three hose-barbs. Beyond the vent is the 1/2" fill tube where the RDS gravity-feed unit is installed if that system is preferred.

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## METHODS OF TRANSFER

With the stock replacement tanks nothing changes in regard to transferring fuel, as the new tank will supply fuel just like the old tank, and once installed, will operate just as the stock tank does. However, with an in-bed model there are several methods of getting that extra fuel into your main tank. A pickup tube, which extends to the bottom of the tank in one corner, is provided in all of the tanks to use with a pump. Any in-bed tank will require that you drill a hole in the bed at an appropriate location to route the supply hose to the main-tank filler or vent. Care should be used to run this hose carefully so as not to kink, chafe, or abrade it when in use.

TDR member "Short Stack" refuels from his tool/tank auxiliary combo by opening his hood, dragging wires to connect the un-mounted pump to the truck battery, sticking a PVC dip tube into the tank fill neck, and then by using a hose and nozzle, refuels his truck. This method requires two people and a little cleanup and disassembly afterwards, but it seems to work for him. If you have a transfer-tank with the pump attached and properly wired, then you can just refuel as you would at a fuel stop using the hose and nozzle. Another simple method is to manually operate an installed electric pump that fills the main tank through a Tee in the existing vent or filler; watching your fuel gauge will tell you when to shut it off. The spare tire tank shown above is used by flipping a toggle switch, activating a selector valve which allows the mechanical fuel pump on the engine to draw fuel from this tank. Having its own level sensor allows the driver to see the amount of fuel left and displays this level on the stock dash gauge.

The tank manufacturers have come up with slick systems that allow you to refuel automatically. Tied into the Dodge 3/4" fuel-vent pipe that runs along the filler tube, these proprietary systems transfer fuel by sensing the fuel level in your main and auxiliary tanks and then pumping fuel from the auxiliary tank when needed. The inline pump is controlled by the brain of these systems and some even have cab-mounted LCD displays to inform the driver of the system status, pump status, and fuel levels in both tanks. The option of fueling manually with a momentary switch is also available.

## THE QUESTION OF GRAVITY-FEED

Although certain states may have their own restrictions on gravity feed systems (you should check first) for diesel fuel, it is legal in the eyes of the DOT (Federal) to gravity-feed as long as it feeds the main tank, not the injectors, or the engine directly. This does not apply to gasoline, which must have the fuel pickup above the level of the fuel when the tank is full. DOT regulations (FMCSA 393.65d) specifically prohibit the gravity feeding directly to the engine. As stated on their site (including the misspelling of the word siphon) is the following:

"(d) Gravity or syphon feed prohibited. A fuel system must not supply fuel by gravity or syphon feed directly to the carburetor or injector."

Section 393.67(5) addresses the location of fuel withdrawal fittings on both gasoline and diesel tanks. Note that it is permissible for a diesel fuel tank to have a low-point withdrawal fitting, as stated in Subpart E - Fuel systems.

"(5) Fuel withdrawal fittings. Except for diesel fuel tanks, the fittings through which fuel is withdrawn from a fuel tank must be located above the normal level of fuel in the tank when the tank is full."

However, it is permissible to gravity feed diesel fuel to the main tank of the vehicle, as doing so does not allow the engine to have a gravity fed supply of fuel. The injection system is still dependant upon the vehicle fuel pump, shutoffs, and filters to supply the fuel. All other requirements of these sections (393.65, 393.67) must be followed when using a gravity-feed system.

Depending on year and model of truck, there may be an issue with the rollover valve allowing fuel to leak out when the main tank is full because of the pressure of the gravity-feed. Some TDR members with pre-1999 trucks have had a problem with this, but most that use gravity feed do not. The fuel cap is vented, but only in the direction of the tank, to prevent a vacuum as the main tank is emptied and, if operating correctly, it should not leak, unless you open it when full. Most in-bed tanks have a drain installed at a low point, which becomes the supply port, and this supply is tied into either the trucks' vent or the main fill neck itself, with a Tee. It is wise to install a shut-off valve at the tank so that the supply can be cut off if needed. Any hole through which a fuel hose passes should have a grommet installed to prevent any damage. If this hose is cut or chafed when the shutoff valve is open, you will drain the contents of the tank on the ground.

The "Diesel Install Kit" manufactured by RDS Aluminum (also available from Northern Tool) allows the installation of a gravity feed system (1999 and newer) that Tees into the main 1 1/2" filler tube, and through the use of a float valve, will shut off the supply of fuel from the auxiliary tank when the level reaches the Tee where the fuel enters the main-tank filler. This kit prevents the fuel from backing up into the fill neck, and seems to work very well. It is supplied with a manual shutoff valve to stop the flow of fuel, or you could install a normally-closed electric solenoid-valve to control the flow from within the cab. When using a gravity-feed system, your dash fuel gauge will show full until the auxiliary tank has emptied into the main tank and the main fuel level begins to drop. This is a very simple system.

## MY CUSTOM AUXILIARY FUEL TANK (Or, I Did It My Way)

With all of the fuel tank background information out of the way I addressed the idea of adding to the fuel capacity of my truck for all of the above stated reasons. With all of the store-bought auxiliary fuel systems available for our trucks, you would think that anyone could find a tank to suit their needs. I, on the other hand, always seem to have a different idea about things than what is offered commercially, and this auxiliary tank thing is yet another situation where what I really want is just not available. So, after much thought, I built my own system that addresses all the issues I found lacking in the other systems. This was quite an undertaking. Oh, by the way, "My Way" does have an associated cost. The sidebar article gives you all of the nitty-gritty.



This is my tank installation completed. It takes up very little room in the bed yet adds an additional 30 gallons of fuel. The tank is fairly invisible with the Masonite panel in place. It does not need to be accessible to fill or to empty the main tank and only takes up 6" of the total bed length. I can pack the bed with camping gear and still have the ability to fill or empty. There is no venting into the camper shell area; it is tied into the main-tank vent.

### My Issue With Location

Where to put an extra tank was my first concern. I could just trade out the stock tank for a larger one and gain 20-plus gallons. The problem there is that I wanted more capacity than that and the high tank cost for such a small amount of extra fuel was not in my favor. I also have my parallel fuel pumps where the tank would sit. Besides, I already have paid for the stock tank and it works, so why toss it out? This led me to the in-bed models, either the tanks alone or one of the toolbox combos. But I have a fiberglass shell on my truck and this prohibits easy filling. I would have to cut a hole in the side of the shell behind the driver's door, or run a filler hose along the inside of the shell from the tailgate to the tank. I didn't want to see a fuel port on my shell (not to mention weather-tight issues if I were to incorporate a door of some sort), and the idea of the indoor plumbing didn't appeal to me either, and would probably cause me to move my truck when fueling if both tanks needed fuel because

diesel hoses might not be long enough to easily allow fueling both positions with one stop. For some reason the non-extension diesel hoses around where I live are usually much shorter than the gasoline hoses. The in-bed tanks don't use space very well either, being deep and boxy, but don't extend full-width, leaving those big gaps of wasted space between sides of the tank and the truck bed. I wanted to retain as much as possible my ability to carry stuff in the truck as well as have the advantage of added fuel.

Gary Wescott did a nice review of a 50-gallon, in-bed tank designed for trucks like mine with a camper shell in TDR Issue 62, pages 124-125 (available online under Digital magazines). This is a nice solution if you don't mind reducing the interior volume of the truck, or cutting a fill neck into your shell. It is a good system but I was looking for another answer.



I fabricated two double hose-barbs on a backing plate that is installed in drilled holes in the side of the bed to allow the transfer of fuel from the in-bed tank to the stock main tank.

The brass manifold was installed in the recess in the side of the interior bed directly behind and to the left of the auxiliary tank, and directly above the pump and main-tank pickup tube. Using this simple method eliminates any fuel hose from passing through a hole in the sheet metal and avoids chafing or kinking issues.

I considered placing the spare tire in the bed, and then building a custom-sized tank for that location, filling it with another polished fuel door in the side of the truck to match the main filler, or hiding the filler behind the left taillight, which could be mounted on a hinge or magnets. I considered the possibility of hiding the filler behind the license plate also. I had made templates out of cardboard and was ready to start in that direction when it occurred to me that putting the spare in the bed was really just trading one space for the other. The spare tire needed the most access, not the tank. The filling issue seemed to be determining how I approached this project. With all but the stock replacement tank, the spare fuel would have to be pumped into the main tank anyway (unless gravity-feed were used) and in that simple fact was found my solution, and led me to the final design that I ended up using.



The front-facing side of the aluminum tank is shaped to follow the profile of the face of the truck bed, and accommodates the reinforced top rail that runs along the top of the bed wall. This allows that space to be used for fuel storage and still confines the tank to a small footprint within the bed of the truck.

### Pump It In – Pump It Out

The secret to my predicament was the diesel transfer pump itself. I found a sliding-vane, 100% duty-cycle, self-priming, reversible diesel pump that would allow me to fill the main tank normally through the stock fuel door, and then by flipping a switch, pump that fuel into my nice neat, perfectly-sized auxiliary tank sitting in the bed of the truck. The transfer pump is good for 6 gallons-per-minute. No additional fill neck, no cutting holes in anything, and no losing valuable square-footage to a bulky in-bed tank. When I needed to transfer the fuel in the auxiliary location to the main under-truck tank, it would be a simple matter of reversing the pump with a flip of a switch. I could now move fuel back and forth between the two tanks, even from inside the truck while driving if I so desired. This would allow me to fabricate my tank utilizing the full width of the bed without wasting the corners, thereby keeping the tank to only 6" in depth off of the front wall of the bed. Here's how I did it.

### The Build

I was going to build the tank from steel because I could have the parts sheared and bent, and do the welding myself. But a few years ago I had a custom aluminum fuel tank for my boat built and it was very reasonably priced so I drew up plans for what I envisioned and sent it around to marine tank fabricators for estimates. I ended up having it made by one of them to my design. Aluminum also offers a significant weight savings over steel. Since the time I had the marine tank built, the price of aluminum, and everything else, has gone up significantly, but I chose to take this path anyway.



This is the aluminum tank sitting in the final location, but not yet installed. You can see that there is no wasted space along the sides of this tank, as in some of the bulkier in-bed models. It also solves the issue of filling, by using a pump to fill, as well as drain it. The black strips are the double-stick Velcro patches used to attach the protective Masonite panel.

The tank sits against the front wall of the bed, and is 66" wide, 18" tall and only 6" deep. It holds a little less than 30 gallons, giving me a total capacity of almost 65 gallons. For every inch of added depth, in the 6" direction, the tank would add about 5 gallons. So if I had made the tank 7" in depth, it would be about 35 gallons and so on. I found the balance between capacity and physical size with my design but if you were to have one built you could adjust accordingly to suit your own needs.

On the top of the tank I have only three fittings, the non-removable pickup-tube which is 3/4", the vent, also 3/4", and the fuel filler. Both the vent and pickup terminate in a 3/4" threaded female bung, to which I have installed 90° brass fittings with a 3/4" hose barb, keeping things low-profile. Though I am not using it now, the filler is a 1 1/2" female threaded bung with a plug in it for future use if needed. I don't need a fuel sender or gauge, but one could be easily added. I specified two full-sized vertical baffles, evenly spaced, to cut down on the fuel sloshing around while driving.

The front of the tank is shaped to follow the contour of the front of our truck beds, where the strengthening bar runs across the top of the bed. I wanted the tank to fit into this area so as not to have any wasted space in front of it that would be better used for fuel storage. I also wanted the tank to fit firmly against the bed. At 7.1 pounds a gallon, my full tank would weigh about 213 pounds, not including the tank itself and I didn't want it moving around back there. I placed a piece of cardboard between the tank and the front wall of the bed to prevent any metal-to-metal contact. With the tank firmly in place, I through-bolted a short piece of angle vertically to the sides of the bed to firmly secure the tank. In the gap at the sides of the tank I wedged 1" pieces of firm rubber to act as spacers to prevent the tank from wandering in a side-to-side direction. These blocks are secured with double-stick tape to keep them in place. I then attached a piece of quarter-inch Masonite, with Velcro, to cover and protect the tank from anything sliding around in the bed. It makes the tank almost disappear.



The main-tank pickup tube is installed in a raised boss almost as if designed for my use. The steel elbow and nipple terminate in the tank with a 3/4" PVC drawtube that drops straight down to the bottom of the tank, allowing fuel to be pumped into the upper tank when needed. The tank was dropped to install this O-ring-sealed connection.



This shows the main-tank pickup tube in place with the tank installed. It is in the perfect position with no clearance issues, and connects to the Jabsco pump with a short run of hose that does not come into contact with any part of the truck bed or tank.

### How to Connect to the Main Tank

After the installation of the tank in the bed, the next issue to address was how to connect it to the main tank in a manner that would allow a leak-free transfer of fuel in both directions. I used two 3/4" double-barbed brass fittings, soldered to a backing plate, and mounted this assembly in the recess that is stamped into the side of the bed and just happens to sit above and near the stock tank location. By drilling two holes to allow the barbs to pass through, I now had two fuel/vent paths that did not create any situation where a hose would pass through any sheet metal hole, eliminating any chance of a surprise chafe-caused leak. This also kept this part of the bed sealed to keep out any water or dust.

All that remained was the simple matter of connecting the tank barbs to these with 3/4" diesel-rated hose and the in-bed part was complete. I installed a 3/4" ball-valve in the supply hose to have the ability to shut off any flow from the auxiliary tank in the event that I had to remove the pump. Without the pump in place the fuel could self-siphon, as the dip tube goes to the bottom of the upper tank and the hosing terminates below it.

One of the hoses is the supply line and the other is the vent. The vent connects with a Tee into the existing filler vent on the truck's fill neck, and this allows the closed-system to transfer fuel back and forth without any air being trapped in either tank. There is no venting into the camper shell; the system uses the vent on the stock tank.

To get fuel into and out of the main tank I fabricated a 3/4" pickup tube, allowing the two tanks to flow fuel back and forth, drawing from the bottom of each tank. I welded a washer on a short black-iron pipe nipple and, by inserting this upwards through a close-fitting hole in the plastic tank, I was able to screw a 90 degree elbow onto the protruding part, sandwiching the tank between washers sealed with O-rings. Onto the threaded lower end of this nipple I attached a PVC threaded fitting glued to a short piece of PVC pipe to drop to within a couple inches of the bottom of the tank. I mounted this draw tube in a molded raised area on top of the tank that was in the perfect location, almost as if it were made for this use. It was necessary to drop the stock tank to do all the needed steps, but it isn't a difficult job at all as long as the tank is near empty. A floor jack with a piece of plywood attached was the answer.



The Jabsco diesel pump I chose is typical of the type of pump used to transfer fuel to your main tank in many of the manufactured systems. This one differs in that it is reversible at the same flow-rate. The hose to the right connects to the fabricated pickup tube in the main tank. The center-off switch is used to reverse polarity to the motor. I installed the screw to restrict the switch to only one direction or off, because I am using a remote-mount switch to control the pump and want to maintain direction of fuel flow consistent with switch position. In use this pump-mounted switch has a rubber boot covering it.

## The Pump and Switch

I mounted the Jabsco reversible diesel fuel transfer pump under the truck near the main tank and just in front of the filler, giving me easy access and short hose runs. A dedicated 8-gauge fused electrical supply and ground to the pump from the battery provides power. I mounted the SPDT center-off switch in the fuel filler cavity where it is easy to get to but out of the way of any accidental activation. Because I have a locking fuel door, it is safe from tampering. The pump draws only 8-amps and I could have just used the switch to control it, but decided to use relays to reverse the polarity, taking the load off the switch. They are mounted above the pump in a waterproof box.



I installed the sealed pump switch in the fuel door compartment where it is easily accessible yet protected from the weather or accidental operation. Because it sits behind a locked door it is not exposed to tampering or the harsh elements of winter. Flipping the switch up fills the auxiliary tank from the main tank and flipping the switch down will reverse this action. The center position is off.

### How Does It Work?

In operation my system is very simple. To fill the auxiliary tank I flip the switch up and let the pump do its job. It takes about 5 minutes to fill. By removing the fuel cap I can hear the fuel flowing into the upper tank and when it approaches full, the sound will change to a gurgle as the fuel starts to reach the level of the vent. When the auxiliary tank is full, the fuel flows through the vent hose and down into the stock fill neck so as not to pressurize the aluminum tank. If I were to forget to turn the pump off, the fuel would just continue to circulate between the two tanks. Now when I fill the main tank again I have two full tanks. It does take a little more time to fill this way, but in my opinion it is a fair trade-off for more room, no extra holes or fill necks, and a fairly invisible installation.



In the completed connection all the hose runs are short and supported from the fittings to the manifold. The ball-valve is able to shut off the supply of fuel to the main tank, if needed. You can see one of two black-painted angles attached to the bed securing the tank against the front wall. The required labeling is also visible on the top of the tank.

When my truck fuel gauge shows that the main tank is running low, I simply flip the switch down and the fuel flows from the upper tank to the main tank, and at a faster rate than when it pumps uphill. By watching the filler neck I can see and hear the fuel when the lower tank is getting full and can turn off the pump to avoid any overflow. In theory, the fuel should circulate between the tanks through the vents if I were to leave the pump running with the cap on, just as in pumping in the other direction. But I don't want to take a chance and pressurize the plastic tank with all of its fittings, as well as the rollover-valve. So in actual practice I never completely fill the lower tank from the upper, but just bring it up to about 3/4 full or whatever amount of fuel I think I'll need to get where I'm going. The idea is to use only as much as needed to continue the trip. This keeps me from having to pump the fuel back up to the in-bed tank again when I do refuel. I originally thought I would install a switch in the cab, paralleled off the one in the filler door to allow fuel transfer while driving, and by watching the fuel gauge I could monitor the transfer, but I have yet to do so only because it is so easy to use with the switch in the filler area. I have not found the need to add it yet, but it would be a simple matter of running a small-gauge (permitted by the use of relays), three-wire harness to a convenient location inside the truck. A momentary switch would be preferable, so as not to forget to turn it off.

### CONCLUSION

No matter which system you buy, use or build, the advantage of carrying additional fuel is a great way to save money and increase your driving range. And although it is still nice to be able to increase miles-per-gallon, if you are looking for an extended range, the ability to buy fuel when you choose to, and the peace of mind knowing that you won't run low, give some thought to adding one of the many available auxiliary tanks systems to your truck.

David Magnoli  
TDR Writer

**I DID IT MY WAY  
(But Should You?)**

After I submitted my article about auxiliary fuel tanks, I received a call from the editor telling me that he thought my article was only half-baked. But he also stated that he had absolutely no interest in a fully-baked article either, not really wishing to print another 12 pages on the subject. He did, however, have questions regarding the cost of my tank project. He asked that I offer more detail about the actual cost compared to a store-bought version. I firmly believe that his sole motivation was to allow you, the reader, to determine for yourself if I was crazy or not, Robert being much too polite to suggest that to me directly. I offer in my own defense the requested accounting.

My new 30-gallon tank, which is not much more than a rectangle, with no sending unit, was, after a bit of negotiating, \$423, with shipping an additional \$142.88, for a total of \$565.88. It is TIG-welded .125 aluminum of equal quality.

I had it built to my drawings by RDS Manufacturing in Perry, Florida, and they did a great job. Wrapped and shipped on a pallet, it was delivered undamaged and on time. Adding more capacity would increase the cost slightly. The many brass fittings I used were from FastFittings.com. They stock all the hard-to-find pieces I needed and they do indeed ship very fast with a flat-rate cost.

The Jabsco marine-grade diesel pump was the second most expensive part. The model I chose was probably much better quality than what I really needed, but I wanted a reliable, well-made pump that would last for years. There are several others available for less, but none that I found that were specifically reversible at the same flow-rate. Not all sliding-vanes are reversible due to the variation of the angle of the sliding vane part. Using a bronze pump housing, with a 100% duty cycle, this is a well-built pump. Prices vary widely, but I found it for \$185 delivered. I also had approximately \$125 in fittings, hose, hose clamps, electrical parts such as wire, split loom, the switch, relays, and miscellaneous hardware items for a grand total of \$875.88

For comparison purposes, the Transfer Flow 37-gallon in-bed tank is priced at \$905 or \$1026 depending on which electronic delivery system is used. Add to that an additional \$140 or \$237 (depending on size) for the filler kit that allows you to fill through the camper shell. When you add shipping you are in the \$1150-1350 range. Installation may be an additional cost if you opt not to do it yourself. My project came in for less, but does not have the automatic transfer function of the Transfer Flow system, which is a substantial part of the cost. Also keep in mind that I went with a custom system because I had a very specific idea about what I wanted and nothing seemed to be available that met my requirements of not needing an additional fill neck to fill the second tank, and also not taking up a lot of bed space. Putting it all together took time of course, but that was the fun part. I also can say that I did it my way, and ended up with a custom auxiliary fuel system that is tailored to my own needs. That is priceless.

For further reading in the TDR magazine about various systems that have been reviewed and installed over the years, the following index is offered for your convenience.

**Issue/Page(s) Article – Manufacturer, Author**

|            |                                                                                                 |
|------------|-------------------------------------------------------------------------------------------------|
| 28/34      | Overview of TRAX system – Transfer Flow, Scott Dalgleish                                        |
| 32/142-145 | 54 gallon Second Generation replacement tank installation details – Transfer Flow, Joe Donnelly |
| 33/8-19    | 65 gallon replacement – Transfer Flow, Andy Coyle                                               |
| 33/63      | 54 gallon replacement – Transfer Flow, Scott Dalgleish                                          |
| 34/148     | 45 and 54 gallon replacement, 38 gallon aft-axle tank – Transfer Flow, press release            |
| 35/127-127 | 98 gallon in-bed – Transfer Flow, Joe Donnelly                                                  |
| 37/148-149 | 38 gallon aft axle installation – Transfer Flow, Joe Donnelly                                   |
| 44/147-150 | 74 gallon in-bed wedge tank install – Transfer Flow, Joe Donnelly                               |
| 49/119     | 60 gallon Third-Gen replacement tank – Aero Tanks, Jerry Neilsen                                |
| 48/166-168 | 56 gallon Third-Gen replacement tank – Transfer Flow, Joe Donnelly                              |
| 50/165     | Tool/Tank Combo – Transfer Flow, press release                                                  |
| 51/120     | 60 gallon replacement tank – Aero Tanks, Jerry Neilsen                                          |
| 52/87      | 2003 and up tank vent modification – David Kelly kit, Scott Dalgleish                           |
| 52/162     | 2003-2006 56 gallon replacement tank – Transfer Flow, press release                             |
| 58/157     | 50 gallon Transfer tank – Transfer Flow, press release                                          |
| 60/144     | 40 gallon Tool/Tank Combo – Transfer Flow, press release                                        |
| 61/90      | 40 gallon Tool/Tank Combo and TRAX II overview – Transfer Flow, John Holmes                     |
| 63/122     | 50 gallon in-bed – Transfer Flow, press release                                                 |
| 68/92      | 98 gallon in-bed review – Transfer Flow, Joe Donnelly                                           |
| 69/92      | 98 gallon in-bed Installation – Transfer Flow, Joe Donnelly                                     |
| 70/92-93   | In-bed tank with camper shell kit – Transfer Flow, Joe Donnelly                                 |

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**David Magnoli**  
TDR Writer

# Lube Oils

ISSUE 76

## LUBE OILS – VERSION 2012

By Robert Patton and John Martin

### A New Inquiry

Last October I received an e-mail from TDR member Desmond Rees:

*I am looking for supplemental information following up John Martin's article from Issue 57 on engine oil. The August 2007 article is somewhat dated. With the switch to the new API requirements for EGR/DPF diesel engines, are there plans to revisit this topic regarding the best engine oils meeting the API CJ-4 requirement? John's article only looked at a handful of the CJ-4 oils and they ranked at the bottom of the pile when compared to the previous generation of oils. Thanks.*

**Desmond Rees**

My response: Prior to Desmond's letter, there were no plans to revisit the topic. However, it has been five years and oils do change. I will purchase and test the CJ oils and John can comment on the data. We will see if John's previous conclusion holds: "If it meets a spec, it becomes a commodity. Low price can be the purchase criteria. Change the oil based on the Owner's Manual recommendations."

Thanks to Desmond for the letter.

### Background Information

It seems like just yesterday that I met lube oil expert John Martin and we collaborated on a series of articles about lube oils.

Ouch! As Desmond reminded me, "yesterday" was Issue 54 of the TDR, which was published in December of 2006. The four-part series that we wrote took a year to complete.

The reason behind the year-long series of articles was the forthcoming change from lube oil category CI+4 (an industry specification that was implemented in 2002) to the new category CJ. The CJ formula of oil was developed for the lower diesel exhaust emissions engines that were being implemented starting 1/1/2007.

I wondered how the lube oil would change. John Martin was the guy to tell me. (More about John in just a minute.)

In a lengthy telephone conversation he shared his opinion about the forthcoming CJ lube oil specification. Bottom line: John felt that the CI+4 oils were some of the best to come out of the respective refineries. In his discussions with those in the oil business, he had formed the opinion that the new CJ oils would not necessarily be new-and-improved.

As I noted, the CJ formula was developed for the new lower emissions diesel engines. From John I understood that the CJ oil would not necessarily be new-and-improved. Without analysis of the lube oils, I asked John what were the proposed changes from the highly acclaimed CI+4 to the new CJ oils. His response: "Robert, this is a lengthy topic, but it is very important for the audience to understand what is happening in the oil business." So, I looked back to Issue 54 and made a couple of tweaks to its contents. The following is the updated text that gives you the insight that you need to understand the CI+4 to CJ change.

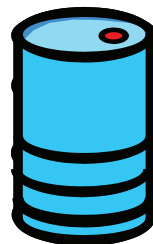
### A Little Lube Oil History

Before we talk about what the additive industry and the oil companies have done to meet the EPA's latest directive, we need a brief lube oil history lesson. Years ago diesels were operated on refined crude oils containing virtually no additive chemistry. As power density increased oil companies found they needed to add specific chemical compounds to the oil to provide performance attributes that crude oils couldn't deliver. The additive industry was born.

Traditionally, each new diesel engine oil specification was issued because available oils couldn't provide the lube oil performance needed. For example, API CE was issued to create oils which solved an oil consumption problem in Cummins NTC-400 engines. For fifty years each new diesel engine oil specification meant a better performing diesel engine oil was available—all the way from API CD to API CI+4.

Today diesel engine oils look like the example shown in figure 1. From 20 to 30% of modern diesel engine oil is additives designed to improve performance in key areas. These additives are carefully engineered mixtures of compounds formulated to pass the various diesel engine tests which define a new lube oil specification like the CI+4 or the new CJ.

### Typical Diesel Oil Composition



- Base Oils: 69-80%
- Performance Package 15-20%
- Viscosity Modifier: 5-10%
- Pour Point Depressant 0-1%

Pour point depressants are used to keep the oil fluid at very low temperatures. (They inhibit wax crystal formation.) Viscosity modifiers are used to make the oil thin out less as it is heated. This makes an oil which we call "Multigrade" and it simply means the multigrade oil acts like a thinner oil at low temperatures and a thicker oil at high temperatures. Multigrade diesel engine oils were a key part of the solution to the excessive oil consumption problem addressed by API formulation CE.

The performance additive package (see figure 2) is a mixture of 8-12 specialty chemicals, each of which is intended to impart specific properties to the oil's performance. The important thing to remember here is that most additive chemicals (particularly detergents) deplete or wear out in service. This is one of the reasons why the oil must be changed. Life was good.

| Typical Diesel Oil Performance Package                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>• <b>Detergents</b><ul style="list-style-type: none"><li>Neutralize Combustion Acids</li><li>Minimize Wear</li><li>Inhibit Rust Formation</li><li>Oxidation Inhibitor</li></ul></li><li>• <b>Dispersants</b><ul style="list-style-type: none"><li>Prevent Agglomeration of Soot Particles</li><li>Suspend Contaminants in Oil</li></ul></li></ul> | <ul style="list-style-type: none"><li>• <b>Oxidation Inhibitors</b><ul style="list-style-type: none"><li>Retard Oil Decomposition</li><li>Slow Deposit Formation</li></ul></li><li>• <b>Anti-Wear Agents</b><ul style="list-style-type: none"><li>Create Sacrificial Film Between Metal Parts</li><li>Minimize Valve Train Wear</li></ul></li><li>• <b>Foam Inhibitors</b><ul style="list-style-type: none"><li>Prevent Oil Foaming</li></ul></li></ul> |

### What Did the EPA Do To Us/Why Do We Need CJ-4 Oils?

First, let's discuss why this new oil was developed. The EPA tightened their exhaust emissions thumbscrew on diesel engines starting January 1, 2007, to reduce particulate matter (PM) and oxides of Nitrogen (NO<sub>x</sub>) emissions even further. To meet those requirements most diesel engine manufacturers resorted to the use of diesel particulate filters (DPFs). A DPF differs from the catalytic converters we have used for years on gasoline engines in that a DPF actually filters the *entire* diesel exhaust stream.

On the surface you wouldn't think this would be a big deal—Europeans have been using DPFs for years. The difference is that Europeans don't accumulate mileage like Americans and they will tolerate much more frequent service intervals. Our EPA has decreed that the new DPFs must go 150,000 miles before needing removal for cleaning. This means the soot collected in the DPF must be burned off in the exhaust system frequently if trap life is to exceed 150,000 miles without removal and cleaning.

Now, don't take me wrong—I'm for a cleaner environment like everyone else is. The problem with the EPA is that they just decree which emissions will be reduced without once considering the cost, the technology needed or its effect on your operation. They refer to that as "Technology Forcing Legislation." In the case of diesel engine oils, the EPA forced the adoption of a low-sulfate ash, phosphorus, and sulfur (low SAPS) oil whose technology hasn't yet been proven extensively in the field.

I don't have to tell you that diesel exhaust is relatively dirty. It consists of lots of soot (That's what turns your oil black!) and unburned residues from both the fuel and the oil. Sulfur in the fuel can significantly hamper DPF performance. That's why the ultra low sulfur diesel (ULSD) fuel was implemented 1/1/2007. Phosphorus and sulfur in the lube oil can shorten DPF cleaning intervals considerably. Phosphorus (P) can "glaze over" and plug the tiny holes in the DPF, making the openings effectively smaller and quicker to plug. Sulfur (S) can "mask" the DPF, making it temporarily less effective. Sulfated Ash (SA) in the lube is thought to build up deposits on the DPF over time. These deposits that originate from diesel fuel and lube oil then make the DPF effectively smaller and quicker to plug.

### What does this mean to you?

Low P means the Feds placed a limit on the amount of Zincdithiophosphate (ZDP) additive which can be utilized. ZDP is the most effective oxidation inhibitor and anti-wear agent currently available. Additive manufacturers are now forced to use more expensive and less effective ashless oxidation inhibitors and anti-wear agents.

Low S means the new oils can't rely on some of the least expensive Sulfur-based oxidation inhibitors used in the past. And, once again, many of the new ashless oxidation inhibitors haven't been thoroughly field proven in heavily loaded trucks. Low S also means more highly refined base oils, which is a positive thing. Average base oil quality is now significantly improved.

Low SA (less than 1 percent weight) effectively places a limit on the amount of detergent which can be used in these oils. But diesels love detergents. In over 25 years of inspecting various diesel engines in the field, I've yet to see one which didn't perform better on oils with higher levels of detergency.

### So, What Oil Should I use?

If you have a diesel engine equipped with a DPF, you should probably use API CJ-4 oils. You really don't have a choice unless you want to clean your particulate trap more frequently. Pay particular attention to oil change intervals.

I know that the major oil marketers are telling their customers that CJ-4 oils are backward compatible (you can use them in pre-2007 engines), and that is somewhat true. But if you use less detergent in an oil, your oil change interval should be shortened accordingly. Oil marketers don't care if you have to change your oil more frequently—in fact, they love it! Remember oil companies are really in the business of moving as much base oil as possible. They love short oil change intervals.

In closing, remember to change your oil as frequently as possible, so we all can generate some more profits for those poor oil companies.

**John R. Martin**  
TDR Writer

## More About the Previous Series of Articles

Way back in Issue 54 I asked John how we might test the CI-4 oils and the new CJs. His response: "That's easy: You spend the \$25 for a complete oil sample evaluation. Be sure the test includes total base number (TBN) and viscosity—and send me the results. Don't tell me what is what. Let's see if there is an obvious difference and let's see who makes the best lube oil(s). Who knows what we will find. Will purchasing a lube oil be as easy as purchasing a commodity? You know, as long as it meets a specification then it is 'good,' therefore you can shop for your lube oil based on price."

Answers to these questions gave me the basis for an excellent article. So, the oil analysis kits were purchased, \$25 x 22 kits (\$550) and I went on a shopping spree for oil, \$15 x 22 oils (\$330). A cool \$880, just so John and Robert would know about lube oils.

Earlier I stated that John was the oil expert. Prior to retirement he was an engineer at Lubrizol, one of the companies that makes and sells the additive packages to the oil manufacturers. And, at John's stage in life, he was/is not beholden to anyone in the industry.

So, what conclusions could one draw from the year-long Martin and Patton examination of 22 different diesel lube oils? I've talked to many TDR members about the series of articles and each one has shared with me their own unique conclusion. Didn't we all read the same article?

I have often stated that, "changing a person's opinion about lube oils is like trying to change their opinion about religion. It is not going to happen." My take-away from the year long, \$880 expenditure (oops... perhaps John Martin has brainwashed me) is as follows:

Back in 1999, it took a series of oil analyses samples before I was comfortable changing my 3,000 mile change-the-lube-oil/guy-on-TV mentality. Then again, it took a series of 22 oil samples to change my mentality concerning lube oil by brand name versus lube oil as a commodity.

I'm on the same page as John Martin; if it meets the specification you can purchase oil like a commodity. Change the oil based on the Owner's Manual recommendations.

## LUBE OILS – VERSION 2012

### Questions for 2012

So, the long answer to Desmond Rees has thus far taken 2.5 pages! However, I felt the background data was necessary before we just jumped into "Lube Oils—Version 2012." The following are the questions I wanted John to help me answer:

- Q1** Could I find the good stuff, an old CI-4 specification oil?
- Q3** Who has the best "John Martin" oil for 2012?
- Q2** How would the CJ-4 oils blended today compare with the same oil that we sampled back in the summer of 2007?
- Q4** What has changed in the world of John Martin in these past five years?

## The Oil Analysis for 2012

As mentioned, back in 2007 we tested 22 different brands of lube oils: everything from Amsoil to Walmart; Caterpillar to John Deere; Red Line to Liqui Moly. The prices ranged from low of Walmart's Super Tech at \$7.68 per gallon to the high of Red Line Diesel Synthetic at \$35 per gallon. If you want the complete list of CI-4 plus and CJ-4 oils that were tested you'll want to look back at Issue 58, pages 52 and 53.

Why 22 oils back then and only 10 oils for 2012? Remember my comment about lube oils, religion and the change of opinion? Well, my opinion has been changed! How so? A look back at Issue 56 gives you some insight into my mindset prior to the testing of the 22 lube oils. Here is the recap:

"When new lube oil is analyzed you can get a good idea of the quality of the additive package that, as learned from Martin's experience, makes up 20–25% of the lube oil blend. Maintaining viscosity at higher temperatures, maintaining high alkalinity (total base number); and protecting against wear with the right blend of molybdenum, zinc, phosphorus and boron are important lube oil attributes. Readings for calcium are a way to measure dispersion detergency.

"In the blind-sampling-from-the-bottle done by [Trailer Life](#) magazine in January 2005, I was greatly disappointed to see that Walmart Super Tech 15W40 diesel oil stood toe-to-toe with other very respected brand names.

"Why disappointment? First, consider what John Martin said, 'Consequently there is less and less difference between engine oil that barely passes the API certification test and one that is designed to pass by a significant margin. Therefore, oils meeting a given performance spec are approaching commodity status.'

"Second, I am not a big fan of Walmart. I could go into a long tirade, but I will refrain.

"Third, for all of my vehicle ownership years (let's see, that is about 37 years) had I been duped? Had I fallen for the marketing hype? I did not want to believe that lube oil is just a commodity. Yet the [Trailer Life](#) grid did not lie."

What story did the forthcoming TDR grid tell?

The previous 22 brand oil test did give me an education. For 2012 I did not feel the need to test every lube oil in the marketplace. As a matter of fact, I only went to two places for the various oils, Autozone (where each oil was priced at \$17.99) and Walmart. The following is the blind sampling data:

## Lube Oils – Version 2012

| Product Identification Chart |                     |           |         |
|------------------------------|---------------------|-----------|---------|
| Item                         | Product             | Viscosity | Price   |
| 1                            | Mobil 1 (Syn)       | 5W40      | \$26.33 |
| 2                            | Motorcraft          | 15W40     | 20.99   |
| 3                            | Walmart             | 15W40     | 10.97   |
| 4                            | Mobil Delvac        | 15W40     | 17.99   |
| 5                            | Chevron Delo        | 15W40     | 17.99   |
| 6                            | Valvoline           | 15W40     | 17.99   |
| 7                            | Shell Rotella       | 15W40     | 17.99   |
| 8                            | Castrol Tecton      | 15W40     | 17.99   |
| 9                            | Warren              | 15W40     | 14.99   |
| 10                           | Shell Rotella (Syn) | 5W40      | 27.99   |

| Sample Description | Viscosity @ 100° | TBN  | Calcium | Magnesium | Phosphorus | Zinc | Boron | Molybdenum |
|--------------------|------------------|------|---------|-----------|------------|------|-------|------------|
| 1                  | 14.1             | 8.84 | 1050    | 777       | 975        | 1110 | 82    | 0          |
| 2                  | 15.5             | 8.17 | 2183    | 9         | 1053       | 1152 | 3     | 1          |
| 3                  | 15.1             | 8.69 | 1135    | 783       | 1020       | 1172 | 0     | 40         |
| 4                  | 14.7             | 9.27 | 1299    | 837       | 941        | 1069 | 64    | 48         |
| 5                  | 16.5             | 8.19 | 1412    | 395       | 1084       | 1250 | 503   | 89         |
| 6                  | 15.5             | 9.15 | 1171    | 970       | 1088       | 1202 | 0     | 43         |
| 7                  | 15.0             | 9.03 | 2209    | 10        | 1039       | 1156 | 35    | 0          |
| 8                  | 15.1             | 9.09 | 2305    | 10        | 1077       | 1169 | 58    | 0          |
| 9                  | 15.5             | 8.7  | 1134    | 787       | 1017       | 1169 | 0     | 40         |
| 10                 | 14.3             | 9.22 | 770     | 1119      | 994        | 1171 | 60    | 58         |

And now, the answers for Lube Oils – Version 2012:

**A1)** I could not find any CI-4 lube oil.

**A2)** I'll turn this answer over to John Martin. John's response:

Robert and TDR audience, remember my often-used statement, "Diesels Love Detergents"? It appears from the oil analysis data that Samples 4, 5, 6, 7, 8, and 10 all have total base numbers (TBN) in excess of 9, which suggests to me that these oil marketers are trying to provide as much TBN as possible given the 1.0% weight sulfated ash limitation imposed by the API CJ-4 specification. They are doing this to satisfy those fleets whose oil change intervals are based on TBN depletion.

Samples 2 and 5 have the least amount of detergency of the oils tested. Sample 5 uses either a borated detergent or a boron-containing oxidation inhibitor. Borated detergents are thought by some to be more effective than traditional detergents. It is also possible that data in the last two columns for sample 5 has been transposed. **(Editor's note: the 503 and 89 numbers are as printed by the lab.)**

My field test experience has taught me that calcium (Ca) detergents are more effective than magnesium (Mg) detergents, so, to answer question 2, "Who has the best oil for 2012?" I think oils 7 and 8 would be the best of the oils you surveyed. Oils 4, 6, and 10 also have high TBN values for CJ-4 oils, but they depend heavily on magnesium detergents, so I don't think they would yield diesel performance as good as oils 7 and 8.

Oils 1, 4, 5, 7, 8, and 10 all contain boron, but I'm certain that the additive chemistry in sample 5 is different than the others (or the last two columns of data for sample 5 have been transposed). Boron

oxidation inhibitors are evidently being utilized to improve the high temperature performance of these CJ-4 oils.

Now, if you allow me to look at the number-to-product identification report I can tell you that oil 5 has been completely reformulated, and I know why. Chevron Delo 400 is the most widely used oil in big trucking fleets. When CJ-4 came about, fleet operators told Chevron they preferred the old CI-4 oil, particularly when they found out that Chevron was going to ask more money for their CJ-4 oil. Neither Chevron nor the fleets would budge off their positions, and big marketers like Chevron only want one oil in their distribution systems. Chevron went back to the drawing board, reformulated, and retested until they could pass the API CI-4 tests with a CJ-4 oil. Then they dropped both earlier oils out of their systems and offered only the new, improved CJ-4 oil. I wonder if the big fleets paid them more money for the new oil?

Mobil and Shell also supply a lot of oil to truckers. If you compare sample 1 (a consumer oil, Mobil 1 synthetic) with sample 4 (Mobil Delvac) you can see that Mobil added more detergency to oil 4 (Ca and Mg) to give their big fleets increased TBN and keep them happy. Fleets wouldn't use the Mobil oil in Sample 1. The Shell samples (7 and 10) are also very interesting. Shell is using different additive chemistry in their 15W40 (Rotella mineral, sample 7) than in their 5W40 (Rotella synthetic, sample 10). I'm guessing that the big fleets are mostly purchasing oil 7. I do not know why the chemistry is so different in oil 10, other than perhaps another additive supplier was able to pass the tests, allowing Shell to get the credentials they desired.

So, once again, my picks are oils 7 and 8. If you religiously adhere to your manufacturer's recommended oil change intervals, oil 3 would be the best performer on a cost per mile basis. Oils 1, 2, and 10 offer the highest cost per mile, so I would avoid them altogether.

**A3)** Now, let's compare the 2007 oils to the 2012 oils. I asked Robert to save you from going back to Issue 58 and present a comparison chart for you.

The CJ-4 Lube Oils Tested in Issue 58 were:

|                                |       |
|--------------------------------|-------|
| Shell Rotella T                | 15W40 |
| Castrol Tecton                 | 15W40 |
| Chevron Delo 400 LE            | 15W40 |
| Cummins/Valvoline Premium Blue | 15W40 |

The following chart gives you the "Then and Now" candidates:

| Price   | Description         | Viscosity @ 100° | TBN  | Calcium | Magnesium | Phosphorus | Zinc | Boron | Molybdenum |
|---------|---------------------|------------------|------|---------|-----------|------------|------|-------|------------|
| \$10.96 | Shell Rotella T     | 15.7             | 8.77 | 2488    | 8         | 1108       | 1147 | 37    | 2          |
| 17.99   | Same 2012           | 15.0             | 9.03 | 2209    | 10        | 1039       | 1156 | 35    | 0          |
| 10.80   | Castrol Tecton      | 14.7             | 7.74 | 2011    | 6         | 876        | 1035 | 0     | 0          |
| 17.99   | Same 2012           | 15.1             | 9.09 | 2305    | 10        | 1077       | 1169 | 58    | 0          |
| 12.99   | Chevron Delo 400 LE | 15.7             | 7.82 | 1593    | 416       | 1156       | 1268 | 83    | 570        |
| 17.99   | Same 2012           | 16.5             | 8.19 | 1412    | 395       | 1084       | 1250 | 503   | 89         |
| 9.98    | Cummins/Valvoline   | 15.6             | 8.42 | 1109    | 827       | 994        | 1041 | 0     | 41         |
| 17.99   | Same 2012           | 15.5             | 9.15 | 1171    | 970       | 1088       | 1202 | 0     | 43         |

Now, to compare the 2012 results to the 2007 table, it appears that Shell has dropped their ZDP content by 10% in oil 7. Before interpreting data from this type of analysis remember that repeatability of these numbers is no better than 10%. Looking at the data in that light, two things could have happened in the last five years. Either the ZDP level could have been dropped 10% to enable Shell's additive supplier to put more detergent in the oil to increase TBN levels, or the data is on the outer edge of the repeatability limits. When comparing today's Shell oils, it looks to me like Shell may be using a different ZDP than they did in 2007.

But, audience, did you notice from your 2007 to 2012 comparative data that all of the oils cost more in 2012? Whether or not the oil marketer changed his initial CJ-4 formulation, he has managed to use the new credentials as a vehicle to raise the selling price of their oils significantly. As I said before, I don't know if oil marketers are getting more for their CJ-4 oils at major fleets, but they are certainly getting more from retail consumers. **(Editor's note: I looked back to November 2007 and a barrel of crude oil was \$88, today it is \$106.)** You and I get to pay for everything!

**A4)** What has changed in John Martin's world in the last five years?

For one thing, I spend much more time researching alternate fuels than diesel lube oils these days. Everyone wants to just jump into the future, be green and reduce our dependence on foreign sources of crude oil without even considering what these moves will do to the poor people who design the vehicles and systems that will have to make that happen.

For example, the public is finally beginning to discover that corn-based ethanol containing fuels (one of the worst jokes of the modern era) are actually worse than gasoline regarding greenhouse gas (GHG) emissions. It has taken the do-gooders billions of our tax dollars to discover what they've been told long ago by fuels researchers. The California Air Resources Board (CARB), a bastion of the most radical environmentalists in the world, has actually had their low carbon fuel standard (LCFS) overturned by a Federal judge.

Secondly, remember how the do-gooders tell us we should all be driving the Toyota Prius (Pious)? The latest GHG emissions research has shown that power plants are responsible for more GHG emissions than transportation vehicles. Where did the do-gooders think that electricity was coming from? Was it magic? Left-wing environmentalists never let facts get in the way of a good story. These are the same radicals who are currently stalling the Keystone pipeline project which could bring much needed crude oil from the North to refineries on the Gulf Coast. After the OPEC countries, China, and Hugo Chavez purchase all that valuable Canadian crude, we will decide to build the pipeline. Our environmentalists are getting to the point where they are very destructive. (My political rant is over. Don't send the editor hate mail.)

Our next new diesel lube oil spec (currently called PC-11) will occur sometime around 2015. The Federal government recently decreed that diesel trucks must provide significantly better fuel economy by 2016. The Engine Manufacturers Association (EMA) has already asked the lube oil industry for some improved fuel economy (FE) oils by 2015 so they can be field tested prior to production. Since the major fuel economy differences are observed by lowering oil viscosity, expect to see some very thin (5W30, 5W20) diesel oils in 2015. Very thin oils probably won't work well in current engines. (More about that in future TDR magazines?) This, too, won't be as easy as the EPA activists think it will be, but, as long as your tax money will hold out, they will be asking you to finance this research.

**John Martin**  
TDR Writer

# The Importance of Using a Paper Filter

ISSUE 80

*From time-to-time we are fortunate to have correspondence direct from Cummins that we can share with you. In this issue let's discuss their online newsletter and an interesting article that they recently published about air cleaners.*

Cummins publishes an online newsletter that is a free service that anyone can sign-up to receive. To do so log-on to [www.cumminsengines.com/newsletter-turbo-diesel.aspx](http://www.cumminsengines.com/newsletter-turbo-diesel.aspx) and follow the prompts.

A screenshot of a web browser displaying the Cummins Turbo Diesel newsletter sign-up page. The page has a red header with the Cummins logo and navigation links. The main content area is white with a red border around the sign-up form. The form includes fields for First Name, Last Name, Company Name, Phone Number, Address Line 1, Address Line 2, City, State/Province, and Zip/Postal Code. There is also a checkbox for 'Do you want to receive the Cummins Turbo Diesel newsletter?' and a 'Sign Up' button.

In their fourth-quarter 2012 newsletter the writers were intrigued by a 1950's video on the "Effects of Dust on Your Engine." You can review that video at the Cummins web site. It is a hoot to watch!

As an update to their findings they wrote an article, "The Importance of Using a Paper Air filter." The article is worthy of reprinting for the TDR audience. Having "been there, done that," I endorse their position on air filtration. At the end of this article I'll add some insight to further substantiate their position.

## From Cummins: The Importance of Using a Paper Filter

Maintaining a clean air filter is very important for the life of your engine. What does dust do to an engine? Let's follow the air as it enters the intake. First, the turbo gets hit with the dust—the blades are spinning as fast as 150,000rpm, and hitting just a small amount of dust at that speed can actually remove material from the turbo blades. Next, the piston rings and engine bore take a beating because the dust acts as an abrasive material, wearing away those two sliding surfaces. Dust can then find its way into the oil by getting past the rings against the bores of the engine. With the oil filter able to hold only so much dirt before plugging and

then bypassing, eventually the rest of the engine bearings suffer.

**Editor's note: Likely before the oil filter is plugged, the rings are too polished and compression is too far gone.**

The factory-pleated paper air filter is a critical element of the air system. It is designed to balance both the flow across the filter and filtered surface area. For example, a driver who uses a particularly dusty route may have 100g of dirt ingested into his air filter. The factory filter at 99.9 percent efficiency will have allowed 0.1g of dirt through the filter and into the engine. An aftermarket cotton-gauze filter or oiled cotton-gauze filter on the other hand typically runs around 97 percent efficient. That 3 percent difference can have a big effect on the life of your engine.

At 97 percent efficiency, 3g equal 30 times more dirt sent through to the engine! This multiplication is true for the life of the filter—the oiled cotton-gauze filter will always let more dirt through.

Now, let's compare and contrast your factory pleated paper air filter with some common aftermarket filters.

Cotton-gauze-style filters have a lower restriction when they are clean, but there are three fundamental issues with them, the first being dust-holding capacity. Due to the thickness of the material used, these filters have very low dust-holding capacity. The way in which they hold the dust means they plug up quickly, and just a small amount of dust makes the restriction increase substantially.

However, the biggest issue with cotton-gauze filters is their filtration efficiency. As mentioned earlier, restriction is based on a combination of the filtration level and the surface area. The total surface area of aftermarket filters is typically much smaller than that of the standard filters, so they manage to offer lower restriction on a clean filter by having much bigger gaps in the material, leading to much lower filtration efficiency.

Finally, oiled cotton-gauze filters are generally cleaned and re-oiled at certain mileage intervals. However, the oil used in these filters is hard on the mass air flow (MAF) sensor and surrounding components. The oil tends to come off these filters as a fine mist and coat the intake systems. This leads to incorrect readings from the already-sensitive MAF sensor.

While all diesel engines are vulnerable to dust, using the recommended factory pleated paper air filter does the best job protecting your engine while balancing flow and restriction. The paper material leads to higher filtration efficiency, which will ultimately lead to a cleaner, stronger Cummins Turbo Diesel.

**Cummins MidRange Engine Team**

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## From the TDR: The Rest of the Story

As recently as Issue 77 I made mention of the paper versus gauze air filters. This “Cummins Column” gives me another opportunity to share the story with you.

Back in the fall of 1999 Cummins tested the K&N filter for air flow and dirt flow. The result: Yes, they flow more air and more dirt. At the time the K&N was the number two selling item at our sister company, Geno's Garage. As much as it could have hurt sales, the folks at Geno's pulled the item from the shelves and no longer offer the K&N line of filters.

That is the abbreviated version, now “the rest of the story.”

From the 1999 test it is interesting to note that the K&N failed both of the Chrysler criteria for an air cleaner: dirt flow through the filter is the obvious; the not so obvious test is dirt-holding capability. In measuring dirt holding, as the term implies, the filter has to hold “x” amount in suspension before it is deemed clogged/too restrictive.

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*Seriously, the Cummins guy was  
tired of the Chrysler guy expecting that  
warranty claims would be paid for engines  
that obviously had been dusted-out.*

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This testing was done because . . . well, because of the Cummins video from the 1950s. Seriously, the Cummins guy was tired of the Chrysler guy expecting that warranty claims would be paid for engines that obviously had been dusted-out. The Cummins and Chrysler folks had the Cummins subsidiary company, Fleetguard “pour the dust” to the filters at their research center. As noted, the K&N filter failed both test. But, you wanted the rest of the story. Oddly enough, the Fleetguard air filter failed the test, too.

Notice, I didn't say the plural, “tests.” The Fleetguard met the all-important Chrysler test for dirt filtration. It did not meet the criteria for dirt holding, effectively meaning under severe dusty conditions the filter would become restrictive quicker than allowed by the Chrysler specification. Bottom line: you would have to change the filter too often.

Looking back to the Geno's Garage catalog of the day, the Fleetguard part number for a Second Generation '94-'98 truck was AF25090. Geno's had been selling the AF25090 since Catalog One in 1996. In the fall of 1999 the part number changed to AF25541.

Subsequent to all of this testing and part number supersession, the folks at Chrysler issued an “information-only” technical service bulletin (TSB) to the dealer network telling them about “Dust-out Diagnosis for Cummins Diesel Engines,” of which the latest TSB number is 09-001-10, dated July 2, 2010. A summarization of this bulletin follows:

This information-only bulletin involves proper inspection procedures to determine engine failure due to dust-out condition. Engines damaged due to infiltration of dirt and/or debris through the air intake system are not warrantable.

This bulletin directs the technician to a document in the STAR center electronic file area. This eFile, along with the inspection and diagnosis procedures in the bulletin, show the cause/effect that occurs with improper filtration and/or upgrade kits, fuel injectors, boxes or downloader devices that increase fuel delivery.

The bulletin is carefully worded. Nowhere in the bulletin does it say that you can't use an aftermarket cotton-gauze filter. It simply gives Chrysler and the dealer network a push-back to the customer that effectively says, “When you select a filter, you are your own warranty station.” Likewise, and this is speculation on my part, should the customer say it is a “warrantable” item from cotton-gauze filter company Airflow-is-More.com, the response from Airflow-is-More would be “Failure of air filter maintenance” caused the engine's demise.

As I mentioned earlier in this saga, the folks at Geno's Garage immediately pulled the K&N filter from their shelves. Shortly thereafter the cotton-gauze filter for diesels in the Mopar Performance catalog was also removed.

In the mid 2000s the folks at Geno's grew weary of telling the cotton-gauze story to folks that were intent on purchasing a cotton-gauze filter. They added back into their catalog a seven-layer cotton gauze filter from aFe. Then in 2007, tired of dealing with aFe's proliferation of part numbers, they changed vendors to Airaid's seven-layer product.

To this day the folks at Geno's will tell you the cotton-gauze story and suggest you either stick with the stock system or focus your attention to ducting cold air to the airbox. And, not wishing to repeat stories ad infinitum that we've covered on the air filter, cold air intake, and the performance you should expect from these types of modifications, I will simply direct you to the coverage of the subject in Issues 56 and 59. These articles are also conveniently found at the Geno's Garage website under “Technical Information” and then the title “Understanding Air Intake Systems,” or at the TDR's website in the digital back issues area.

Now, if only the folks at Cummins had installed a good filter prior to the turbocharger in their 1952 diesel-powered car that sat on the pole position at the Indianapolis 500. If they had done so, they might have rewritten the history books. That engine failed at lap 71 of 200 due to rubber tire debris being ingested into the turbo. Live and learn.

Yes, this is the “Cummins' Column” and I found a good article about their 1952 race efforts on the internet. That article follows on pages 40-41.

**Robert Patton**  
TDR Staff

# Understanding Air Intake Systems – Part One (Airflow)

ISSUE 56

## UNDERSTANDING AIR INTAKE SYSTEMS| PART ONE (AIRFLOW)

by Pete Tomka – Performance Systems Manufacturing

Air intake systems appear to be a mystery to most readers. Sometimes they improve power, other times they don't. This two-part article will help to explain how an air intake system works using engineering principals and dynamometer test data. Part 1 will discuss airflow and show the effects different intake components have on engine power. Part 2 will discuss air density and show the effects air density has on engine power.

Turbocharged diesel engines operate differently than a normally aspirated gas engine. Diesels typically operate under boost conditions, even at idle and generally never see a vacuum. There is no throttle plate(s) to control the amount of air that enters the engine. The typical normally aspirated method of moving air into the cylinder, as the piston travels down the bore, is now performed by a turbocharger that force-feeds six big cylinders.

To understand how an air intake system works, you must first understand airflow. It is difficult to visualize how air moves through an intake system. Automotive engineers use flow meters and pressure gauges to measure the air as it passes through various intake components. A large drop in pressure between components is an indication of a restriction. Air always moves from a high-pressure area to a low-pressure area. This phenomenon can be compared to our weather, as wind is created by air moving from high pressure to lower pressure cells. The greater the pressure difference between these weather cells, the faster the winds blow. The air intake system operates in a similar manner.

From your physics class in high school, you may remember that atmospheric air pressure at sea level is 14.7 pounds per square inch (psi). This is the weight of one square inch column of air extending from the ground surface to the outer limits of our atmosphere. In Denver, Colorado, at 5,280 feet elevation, this number is 12.1-psi, since the height of the air column to the tip of our atmosphere is less. When this atmospheric pressure is added to, or subtracted from, our test instrument gauge pressure reading, the sum of the numbers is called absolute pressure. For example; 14.7-psi atmospheric pressure plus 20 psi boost gauge pressure is 34.7-psi absolute pressure.

In all air intake systems, there is a pressure loss as air flows through the system. The amount of pressure loss will depend on the quantity of air, measured in cubic feet per minute (CFM), flowing through the intake. Pressure loss is also referred to as pressure drop as this is what is actually happening. If we assume we have a one-psi pressure drop through our intake system (which can happen if we are flowing huge quantities of air), the absolute pressure at the turbocharger is 14.7-psi minus 1-psi or 13.7-psi. The greater the

absolute pressure is at the turbocharger compressor wheel, the higher the discharge absolute pressure will be when air exits the turbo compressor. Higher discharge pressure equates to higher boost pressure on the boost gauge. The spinning compressor wheel creates the low-pressure area that causes air to flow from the air box to the turbocharger. The faster this wheel turns, the greater the low-pressure area becomes, and the faster the air will move towards the turbocharger. The pressure drop between the air box and the turbocharger compressor wheel will continue to change to satisfy the engine's air quantity needs as the boost and RPM change from throttle movements.

## MASS AIRFLOW

There are numerous physics and engineering formulas to predict and model airflow. We will only discuss one that should be of most interest to TDR members, which is mass airflow (MAF). The effect of MAF is not only important in the design of an air intake system, but equally important to most other power enhancement components that we install under the hood. MAF is the pounds of air that is consumed by an engine every minute. Higher MAF number means more air molecules are ingested by the engine every minute, resulting in more power from the engine. MAF is obtained by multiplying the CFM of air that enters the engine by the density of the air. Our truck's manifold absolute pressure/temperature (MAP) sensor provides data to the ECM to calculate the MAF number numerous times per second to ensure the correct amount of fuel is injected into the combustion chamber. Part 1 of this article will concentrate on the CFM aspect of the MAF equation. The air density component will be covered in Part 2.



**The best mass airflow enhancers: Intercooler (for increased air density) and turbocharger (for increased airflow)**

Aftermarket air intake manufacturers often advertise the airflow improvement their system provides over the stock intake. To determine the increased CFM airflow, a device called a flow bench is used. A flow bench is a test tool that has a series of vacuum pumps, a flow meter and pressure gauge. The air intake system to be tested is mounted over the flow bench inlet port. A duct connects the port to the vacuum pumps. Inside the duct, the gauge sensors are mounted. The pumps create a vacuum in the duct and intake system. Atmospheric pressure on the outside of the air box causes air to flow toward the pumps. The amount of air that flows through

the intake system, and the pressure drop required to flow that same amount of air, can then be measured. It is not uncommon to see an aftermarket air intake system with airflow of 50% more than stock at the same pressure drop. What does this test prove? A flow bench test confirms that there is a difference in airflow resistance between intake systems. The lower the air flow resistance in an intake system, the greater the potential for the turbocharger to make more boost. More boost generally equates to more power. However, an intake system that has less measured airflow resistance on a flow bench is no guarantee that it can generate more power. The temperature of the intake air entering the turbocharger must also be considered. A much more accurate test to evaluate the gain from any air intake system is to install the air intake in the vehicle (with the hood closed) and run a chassis dynamometer or real-world test. After all, who drives a flow bench around town? You'll find that the difference in airflow resistance and heat an air intake system is exposed to once it is installed in a vehicle cannot be duplicated in a laboratory flow bench test. A real-world test drive that records air intake temperatures and vehicle acceleration rates would be the ultimate test to verify the benefits of an air intake system.

One of the biggest myths in the industry is that a new air intake system will increase airflow. The engineering formula used to calculate airflow requirements for any turbocharged engine include only four variables. These are: engine displacement, engine RPM at maximum horsepower, engine volumetric efficiency, and boost pressure at maximum horsepower. Unless we take our engine apart, the only airflow variable that can be easily modified is to increase turbo boost or replace the turbocharger with one that is more efficient or moves more air. There are no other products on the market that will increase airflow. Some aftermarket air intake systems may reduce the pressure drop between the air box and the turbocharger, thus allowing the turbocharger to create more boost, but only if the engine control module and turbo wastegate will permit this to happen. On the '04.5 and newer trucks, the stock ECM and electronic controlled wastegate will not allow additional boost to build up over the stock 30-31-psi.

## THE MAGAZINE TEST

Diesel Power magazine (October '06 Issue) did an air intake test comparison between the stock air intake and six aftermarket air kits using a stock '05 Turbo Diesel pickup. They were surprised at their findings that not one aftermarket intake kit would increase horsepower over the stock systems. They complimented the Dodge engineers on their fine work in their design of the air intake system. Why did none of the aftermarket air intake kits increase the power over stock? Possible reasons could be: a) The actual air flow resistance (pressure drop) of the "installed" aftermarket intake systems closely matched the air flow resistance of the stock air intake, b) The hood may have been closed, which permitted underhood hot air to enter the intake air box and thus reducing air density, or c) The ECM would not allow the turbocharger to make more boost to increase power. What happened to some manufacturers claims of up to 11 horsepower gain? Maybe these numbers were derived from a flow bench test!

The stock air intake system appears to be as good as any aftermarket air intake. One might ask; is there any room for improvement on the stock system? Let's find out.

## TESTING THE COMPONENTS

Our testing involved the Third Generation trucks with the air box located at the radiator support panel. The Second Generation trucks have the air box located at the cowl, which exposes the box to much more heat from the turbocharger and exhaust manifold. Although, the dyno numbers will not apply to the '94-'02 trucks, the physics, engineering principles and discussions should be of great interest to all Second Generation truck owners.

Thanks to Clint Cannon, at ATS Diesel Performance, we were permitted to use their Mustang chassis dynamometer for two days. We tested three air boxes, four stock replacement panel air filters, one conical filter, six intake tubes and the Turbo Air Guide (TAG). Together, we created over 20 combinations of different intake assemblies. Tests were run at the stock fuel setting and at an 80 horsepower fuel setting using a TST Power MaxCR.

### Components tested

The three air boxes were: stock air box; Performance Systems Manufacturing modified stock air box; and an aFe "semi-heat shield" metal air box #54-10411.

Five air filters were tested: Stock Mopar filter, #53032700AB; aFe Pro-GUARD 7, #73-10102; aFe Magnum Flow, #30-10102; Amsoil Ea, #A189; and the aFe Pro-GUARD 7, #73-98009 conical.

Six intake tubes were used in testing: Stock '04; Stock '05; Stock '04 without the silencer, silencer replaced with a Performance Systems Mfg. four-inch diameter straight tube; aFe Torque Tube (this steel/rubber tube is now discontinued); aFe Torque Booster plastic tube; and Diesel Power Products "Cool Tube" silicone rubber tube.

A Diesel Power Products "Turbo Air Guide" (TAG) was also tested.

### Test truck and test procedure

The test truck was a '04 3500 dually, with a 305 hp High Output Cummins, six-speed and a 4:10 rear gear. Dyno runs were performed in fifth gear starting from 32 mph and ending at 67 mph to capture the boost, torque and horsepower between 1400 and 2900 rpm. The TST PowerMax CR was set at the stock fuel level (0/0) for the stock test runs and at fuel enhancement level (2/5) to produce 80 additional horsepower. Other than the TST box, the truck was stock. The 2/5 fuel enhancement level was selected to keep the maximum torque below 750 lb-ft. The Mustang Dyno boost sensor was inserted into the intake plenum to allow continuous recording of boost pressure along with the horsepower and torque numbers.

The tests began using the most restrictive air intake assembly and progressed to the least restrictive assembly. The restriction values were based on the reading from a pressure sensor located just in front of the turbocharger compressor wheel. Intake restriction (pressure drop) was recorded between the air box and turbocharger compressor wheel while under full boost. Pressure drop is expressed in "inches of water column." We were very interested in how airflow restriction from the different intake components affected maximum torque, peak horsepower and boost.

The power numbers listed in the summary chart are dynamometer horsepower and torque values. Understand what these numbers mean and use them to impress your friends, but don't expect these numbers to reflect real-world driving performance. Dyno testing is usually performed in a semi-controlled environment using the same test procedures for all tests. We chose to use a "sweep" test with a load applied to the engine for 10 seconds. Just prior to the test run the engine was brought up to operating temperature and the hood was up to vent the under-hood heat from the engine compartment and to provide cool air for the conical-type air filters. We all know real-world driving conditions are far different from the dyno shop test conditions, but our test procedure was easily duplicated and ideal for testing all the different components of the intake system.

### Test observations

Before you look at the dyno test results, you first need to understand pressure drop through the intake components. In this evaluation we are testing only three components of the intake system: the air box; the air filter; and the intake tube. Each component has a particular resistance to air flow. The component with the most airflow resistance should be upgraded first; otherwise the full power benefit of any other component will not be fully realized. If one studies the summary dyno chart, they will find that the first component that should be replaced is the stock filter, followed by increasing the air inlet area into the stock air box and ending with replacing the stock intake tube. Prior to this testing, the belief was that the air box inlet area was the biggest restriction in the stock intake system.

### Air Filters

There are at least four different media used in air filters: paper; cotton gauze, foam and the new dry element. They all have their own advantages and disadvantages. We will not discuss those in this article, but will only concentrate on the airflow resistance of each medium. From our dyno and pressure sensor testing, the most restrictive filter medium is the paper element, then foam, followed by the dry element and then the cotton gauze. If maximum dirt filtration is the priority, one can see how much a type of filter medium will affect engine power by looking at the dyno summary chart.

Typically, the less restriction (pressure drop) the filter has, the more potential horsepower the engine can realize. Manufacturers typically measure air filter performance on a flow bench and

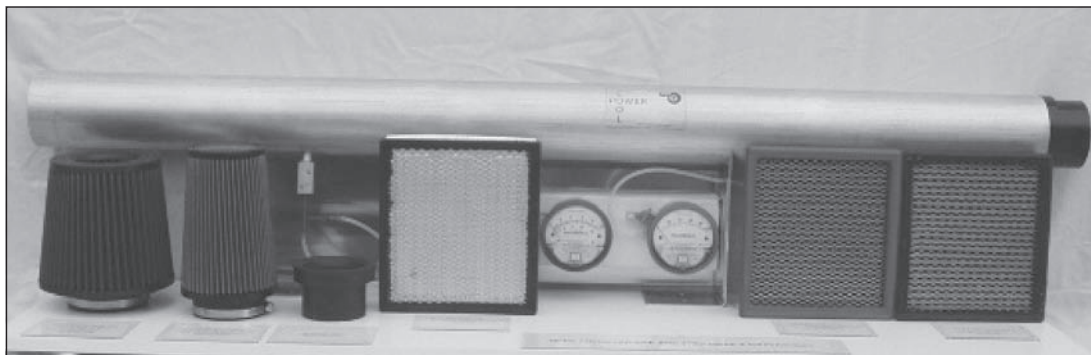
provide a CFM airflow number at a particular standard of the industry pressure drop, usually 1.5" of water column. This number has no real value to the CFM of air the filter can flow. Air flow numbers may be useful when comparing air filters from different manufacturers PROVIDING you are comparing the identical size air filters. However, flow rates provided by manufacturers typically don't apply to the filter size one is using. Besides airflow restrictions, we should also be concerned with the filter efficiency and dirt/dust holding capability. This type of test data is almost impossible to get from filter manufacturers as they typically claim it is proprietary information.

One interesting observation occurred during the dyno testing of these four different filter media. Higher air flow resistance or pressure drop across the filter will produce better turbo boost response and low end torque at the sacrifice of less top end power. For example see the Dynamometer Summary Chart at the end of this article and compare Test 1 torque number at 1800 rpm to Test 5 torque number. For enhanced fueling, compare Test 12 torque number to Test 16. In both cases, the stock filter made more power quicker than the Pro-GUARD 7 filter. Boost response is the timed period between hitting the throttle at a low engine rpm, zero boost, and stopping at the time of appreciable boost. The higher the torque at 1800 RPM, the faster the turbo spools.

Although we did limited testing on the Amsoil Ea filter, it appears the stock Mopar and Amsoil Ea nano-fiber filters provide the same performance. They both enhanced low-end torque below 2000 rpm and relinquish some top end power to the other filters tested. However the two to three horsepower loss above 2700 rpm may not be worth the trade off in air filtration efficiency, especially for those individuals who do light towing or drive in dusty locations.

The aFe Pro-GUARD-7 filter with its seven layers of filtration does allow the engine to make more torque and horsepower compared to the paper or dry element filters (compare Tests 1 and 5 for stock fueling and Tests 12 and 16 for enhanced fueling); however, there is typically a slight reduction in filtration efficiency and dirt/dust holding capability.

The aFe Magnum Flow filter has five layers of filtration and, surprisingly, only makes one HP more than the Pro-GUARD-7 filter (see Tests 9 and 11 for stock fueling and Tests 24 and 25 for enhanced fueling). We also found this same minimal improvement in other dyno tests on vehicles making over 450 horsepower. We question if the small gain in power, using this filter, is worth the decline in filtration efficiency and dirt/dust holding capability.



Some of the air filters tested, 2 conical (left), stock paper Mopar (Center), 2 stock replacement gauze (Right)

We do not endorse any of the above filters over any others. There are numerous filter suppliers that offer the same or similar stock replacement filter products that may perform equally well. We simply don't have the time or funds to test them all. The purpose of our tests was to show how filter media affect performance.

## Air Box

The three air boxes we tested were the stock '04 unit, a Performance Systems Mfg. (PSM) modified stock air box with an inlet duct running from the bottom of the air box to the underside of the vehicle, and an aFe semi-heatshield type open metal box.



**Stock Sealed Air Box (Upper Left), aFe Semi-Heat Shield Air Box (Lower Left), PSM Modified Sealed Stock Air Box (Right)**

The Dodge engineers did a great job of designing the air intake system in our Third Generation trucks for the airflow and power they were designed for. In '04.5 with the introduction of the 600 engine, the factory made changes to the air box, the method of supplying air to the box and in the intake tube design. The stock air box was improved by increasing the air inlet area into the box from approximately 19 to 26 square inches. Dodge also added an additional source of cold air into the air box. In the '03 to '04 models, the air box received all the intake air from the passenger side fender. A plastic liner was installed on the inside face of the fender to isolate hot under-hood air from getting into the fender. In '04.5, a vertical baffle was added below the air box to allow intake air to be picked up at the bottom lip of the plastic wheel well in front of the tire. For some reason, the plastic liner at the fender was discontinued on the '04.5 and newer trucks. We can assume these changes were required to keep the pressure drop through the intake system at a reasonable level for the additional airflow generated with increased boost for the higher 325 horsepower rating. The stock '04 air box was used as the baseline to evaluate the two other air boxes tested.

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*The Dodge engineers did a great job of designing the air intake system in our Third Generation trucks.*

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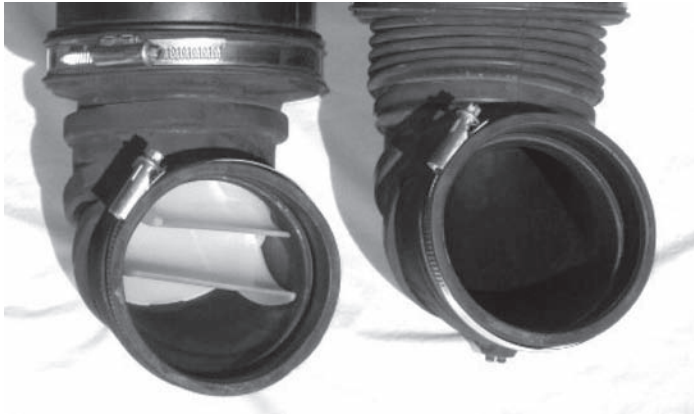
**Arrow pointing to vertical baffle used on '04.5 and newer trucks to keep under-hood heated air from entering the air box**

The PSM box increases the air inlet area of the sealed stock air box by 12 square inches and delivers cool air from under the vehicle to the air box through a flexible four-inch diameter duct. A sealed air box is when 100% of the intake air is coming from outside the engine compartment. The majority of factory air boxes use this design to ensure maximum density air enters the engine. Looking at Tests 5 and 6 and Tests 16 and 17 in the Dyno Summary Chart, we find that the additional air to the PSM modified stock air box improves the turbocharger's boost response, resulting in slightly more power throughout the rpm band and also increasing peak horsepower above 2700 rpm.

The aFe semi-heat shield unit is designed to partially shield under-hood heat from the air filter, but does not prevent hot air from entering the air filter. This kit contains a large conical air filter that has almost twice the filter area of the stock filter. During the dyno runs, the hood was left open to expose the filter to unrestricted and cooler air outside the engine compartment. The purpose of testing in this manner was to determine if the stock or PSM sealed air box could make the same power as a shielded type aftermarket air intake system. Tests 19 and 20 show that the PSM air intake made the same horsepower and torque numbers as the aFe intake system. Why does a filter that is almost twice as large as a stock filter and open to the atmosphere make the same power as a filter that is fully enclosed in a sealed air box? Remember that engine airflow needs are not dependent on air filter or air box design. Engine airflow requirements are determined by the four variables (engine displacement, engine RPM, VE and boost). Since none of the four variables changed and the air box pressure drop of each intake system was identical, the power output remains unchanged. You may ask what happens to the aFe systems power when the hood is closed? That question will be answered in Part 2 of this article when the detrimental effects from hot under-hood air and resulting lower air density will be discussed.

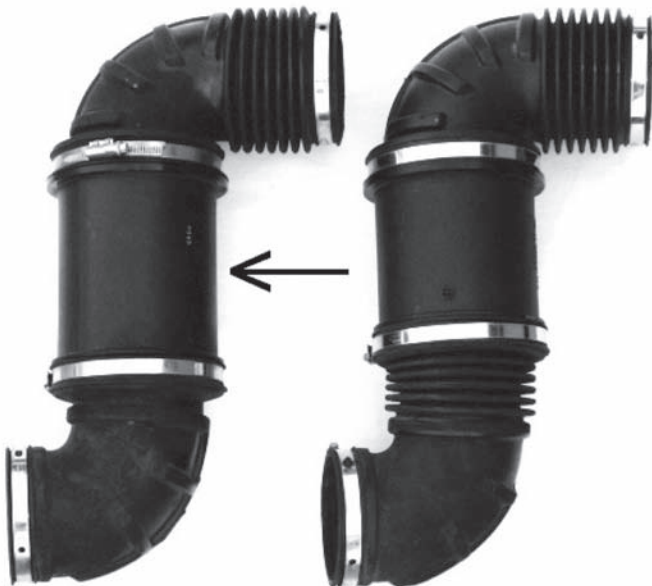
## Intake Tubes

Is the '04.5-newer intake tube design an improvement over the '03-'04 tube? The answer depends on the engine horsepower level. The '04.5-newer tube uses a longer silencer and plastic turning vanes placed inside the turbo elbow. The '03-'04 tube only has the silencer. At stock power, from Tests 3 and 4, the '04.5-newer intake tube is better than the '04 tube. At the 80 HP fueling level, Tests 13 and 14, show the '04 intake tube is better. However, the definition of better is relative, as in both tests you are looking at a 2.8 or less torque or horsepower number difference.



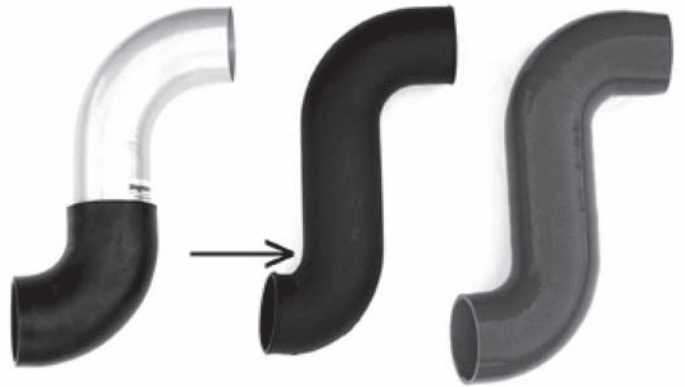
Turning vanes in lower elbow of '05 Stock Intake Tube (Left), Stock '04 Intake Tube elbow (Right)

Does removing the intake tube silencer increase power? In examining Tests 3 and 7 for the stock fueled engine and Tests 17 and 19 for the enhanced fueled engine, the answer is yes with a gain of 1.0 and 2.0 horsepower respectively. At these small numbers is it really a gain or dyno error? The other benefit from removing the silencer is that our tests show an improved turbo boost response and spool up.



'05 Intake Tube (Left), '04 Intake Tube (Right). Note increase length of '05 noise silencer (arrow)

Will replacing the stock intake tube with an aftermarket tube produce more power? All three aftermarket intake tubes tested did improve horsepower, torque and turbo boost response over the stock intake with or without the silencer installed. Are the slight improvements worth the money? You be the judge. As a rule, the tubes with the larger inside diameter and bend radius will have less airflow resistance and provide slight improvement in power. The tubes with the largest inside diameter and bend radius were the DPP "Cool Tube" and aFe steel "Torque Tube." Consequently, these two tubes made slightly more power than the aFe plastic tube. See Tests 22, 23 and 24. Our testing shows that inside tube diameters that are larger than four inches have no power gain on engines that produce less than 400 rear wheel horsepower.



aFe steel/rubber Torque Tube (Left), aFe plastic Torque Booster tube (Middle), DPP silicone rubber Cool Tube (Right). Note tight bend in plastic tube (arrow) which increases air flow restriction

## Turbo Air Guide

The turbo air guide, better known as the "TAG," is a controversial item. Many TDR members say they see mileage improvements, better turbo response and lower EGTs when they install this device in front of the turbocharger. Other members see no improvements from stock. For the effect of the TAG compare Test 6 and 8; 17 and 18; and 21 and 24. You be the judge.



Diesel Power Product's Turbo Air Guide

## SELECTING THE RIGHT AIR INTAKE COMPONENTS

There is a mathematical aphorism that says “The whole is greater than the sum of its parts.” If we look at the Dyno Summary Chart, we find that this cliché also applies to air intake components. When an aftermarket air filter, air box and intake tube are tested separately, the sum of the power change from each component over the stock intake system is less than the power improvement gained if all three components were tested together. See chart below for the data:

| Stock Fueling |        |      |         | 80 HP Fuel Enhancement |        |      |
|---------------|--------|------|---------|------------------------|--------|------|
| Test          | Torque | HP   |         | Test                   | Torque | HP   |
| 5             | +1.0   | +3.2 | Filter  | 16                     | +3.6   | +2.5 |
| 3             | -2.0   | +0.4 | Air Box | 14                     | +2.8   | +1.4 |
| 2             | +6.1   | -2.5 | Tube    | 15                     | +5.8   | +1.7 |
|               | +5.1   | +1.1 |         |                        | +12.2  | +5.6 |
| 9             | +4.9   | +6.8 | 3 above | 24                     | +13.5  | +9.9 |

When the Pro-GUARD 7 air filter, PSM modified stock air box and DPP intake tube were tested as a complete system (Tests 9 and 24), the torque remained approximately the same as when each component was tested separately; however, the horsepower increased significantly. This power increase is the result of using intake components that enhance each other's potential to reduce the pressure drop of the intake system. Remember, the lower the pressure drop is at the turbo, the more boost the turbo will make, and the more engine power will be generated.

## DYNAMOMETER SUMMARY CHART

### STOCK FUELING

| Test | Max Boost | Torque@1800 RPM | Max Torque @ approx. 2250 RPM | Pressure Drop @ Turbo @ 2900 RPM | Max HP @ approx. 2850 RPM | Intake System Component Description                                  | Improvement in Max Torque | Improvement in Max Horsepower |
|------|-----------|-----------------|-------------------------------|----------------------------------|---------------------------|----------------------------------------------------------------------|---------------------------|-------------------------------|
| 1    | 22.1      | 447             | 514.0                         | 18.0                             | 266.7                     | Stock '04 air intake w/ Mopar filter                                 | Base Line                 | Base Line                     |
| 2    | 22.5      | 468             | 520.1                         | 12.8                             | 266.2                     | Stock air box, Mopar filter & “Cool Hose” rubber intake tube         | 6.1                       | -2.5                          |
| 3    | 22.2      | 444             | 512.0                         | 16.0                             | 269.1                     | PSM cold air box, Mopar filter & stock '04 intake tube               | -2.0                      | 0.4                           |
| 4    | 22.3      | 436             | 511.3                         | N/A                              | 270.4                     | PSM cold air box, Mopar filter & stock '05 intake tube               | -2.7                      | 1.7                           |
| 5    | 22.2      | 443             | 515.0                         | 17.2                             | 271.9                     | Stock '04 air intake & Pro-Guard 7 filter                            | 1.0                       | 3.2                           |
| 6    | 22.3      | 447             | 516.4                         | 15.2                             | 272.5                     | PSM cold air box, Pro-Guard 7 filter & stock '04 intake tube         | 2.4                       | 3.8                           |
| 7    | 22.3      | 456             | 516.2                         | 12.5                             | 273.5                     | PSM air box, Pro-guard 7 filter & stock '04 intake tube w/o silencer | 2.2                       | 4.8                           |
| 8    | 22.3      | 444             | 515.6                         | N/A                              | 275.2                     | PSM cold air box, Pro-Guard 7 filter, stock '04 intake tube & “TAG”  | 1.6                       | 6.5                           |
| 9    | 22.7      | N/A             | 518.9                         | 10.0                             | 275.5                     | PSM cold air box, Pro-Guard 7 filter & “Cool Hose” intake tube       | 4.9                       | 6.8                           |
| 10   | 22.5      | 432             | 516.5                         | N/A                              | 275.8                     | PSM cold air box, Pro-Guard 7 filter, “Cool Hose” & “TAG”            | 2.5                       | 7.1                           |
| 11   | 22.7      | 463             | 519.5                         | 7.7                              | 276.6                     | PSM cold air box, Magnum Flow filter & “Cool Hose” intake tube       | 5.5                       | 7.9                           |

### 80 HP FUEL ENHANCEMENT

|    |      |     |       |      |       |                                                                                             |           |           |
|----|------|-----|-------|------|-------|---------------------------------------------------------------------------------------------|-----------|-----------|
| 12 | 23.9 | 512 | 712.1 | 18.0 | 352.4 | Stock '04 air intake w/ Mopar filter                                                        | Base Line | Base Line |
| 13 | 24.0 | 477 | 711.9 | N/A  | 351.1 | PSM cold air box, Mopar filter & stock '05 intake tube                                      | -.02      | -1.3      |
| 14 | 24.1 | 504 | 714.9 | 16.0 | 353.8 | PSM cold air box, Mopar filter & stock '04 intake tube                                      | 2.8       | 1.4       |
| 15 | 22.7 | 519 | 717.9 | 12.8 | 354.1 | Stock air box, Mopar filter & “Cool Hose” rubber intake tube                                | 5.8       | 1.7       |
| 16 | 24.1 | 497 | 715.7 | 17.2 | 354.9 | Stock '04 air intake & Pro-Guard 7 filter                                                   | 3.6       | 2.5       |
| 17 | 24.2 | N/A | 720.1 | 15.2 | 356.8 | PSM cold air box, Pro-Guard 7 filter & stock '04 intake tube                                | 8.0       | 4.4       |
| 18 | 24.1 | 504 | 716.7 | N/A  | 357.2 | PSM cold air box, Pro-Guard 7 filter, stock '04 intake tube & “TAG”                         | 4.6       | 4.8       |
| 19 | 24.2 | 517 | 715.9 | 12.5 | 358.8 | PSM air box, Pro-guard 7 filter & stock '04 intake tube w/o silencer                        | 3.8       | 6.4       |
| 20 | 24.5 | 529 | 716.3 | N/A  | 358.8 | aFe Stage 1 intake, Pro-Guard 7 conical filter, stock '04 intake tube w/o silencer, hood up | 4.2       | 6.4       |
| 21 | 24.8 | 504 | 719.9 | N/A  | 359.5 | PSM cold air box, Pro-Guard 7 filter, “Cool Hose” & “TAG”                                   | 7.8       | 7.1       |
| 22 | 25.2 | 517 | 722.5 | 10.5 | 360.5 | PSM cold air box, Pro-Guard 7 filter & plastic intake tube                                  | 10.4      | 8.1       |
| 23 | 25.3 | N/A | 721.4 | 9.7  | 362.3 | PSM air box, Pro-Guard 7 filter & metal/rubber intake tube                                  | 9.3       | 9.9       |
| 24 | 25.1 | 521 | 725.6 | 10.0 | 362.3 | PSM cold air box, Pro-Guard 7 filter & “Cool Hose” intake tube                              | 13.5      | 9.9       |
| 25 | 25.1 | N/A | 724.5 | 7.7  | 362.7 | PSM cold air box, Magnum Flow filter & “Cool Hose” intake tube                              | 12.4      | 10.3      |

## SUMMARY

- MAF represents the number of pounds of air that is consumed by an engine every minute at a given boost and engine rpm. A higher MAF number means more air molecules are ingested by the engine every minute which will produce more power.
- Testing aftermarket air intake systems on a flow bench is not a good method for predicting performance improvements. Installing the intake system in the vehicle, with the hood closed, before running a chassis dynamometer test or running real-world acceleration tests, is the preferred method to evaluate performance differences.
- Engine's CFM needs are determined by only four variables: engine displacement, maximum engine RPM, engine volumetric efficiency, and maximum boost pressure. Increasing turbo boost or replacing the turbocharger are the easiest methods to increase CFM. No other bolt-on products will increase airflow.
- Diesel Power magazine tested six aftermarket air intake systems and none of them made more power than the stock intake.
- Dyno horsepower and torque numbers are not true real-world power numbers as the density of the air entering the engine from the heat generated from under the hood is not typically accounted for during this type of testing.
- Each air intake component has a particular resistance to air flow (pressure drop). The component with the most pressure drop should be upgraded first (air filter); otherwise the full performance benefit of any other component that has a lesser pressure drop effect will not be fully realized.
- Filter manufacturers provide a CFM airflow number at a set pressure drop which has little value in determining which air filter satisfies the engine's air requirements.
- Air boxes, which are sealed from under-hood heat and receive 100% of the intake air from outside the engine compartment, can provide the same dyno power as the more common heat-shield conical filter type aftermarket boxes.
- At stock power, the stock intake tube is satisfactory. Aftermarket tubes with a larger inside diameter than stock and increased bend radius complement the additional fuel provided by a performance module.

**Pete Tomka**  
**Performance Systems Mfg.**

## SIDEBAR COMMENTS

**by Joe Donnelly**

Lower temperature intake air helps air density and ultimately helps to moderate exhaust gas temperatures. Larger capacity air boxes and filters help the turbocharger to draw all the air it needs for high power, high boost situations. With those generalizations being on the table, we can move to practical situations.

Back in TDR Issue 37, page 26, we covered several air systems with respect to dyno testing. The main part of the story that was lacking was any contribution from "ram air" with truck speed on the road. Here are a few conclusions from that article: With a Second Generation Turbo Diesel, the stock air box and filter are good up to 500 horsepower. Several filters were tested that performed as well as no filter at all in terms of horsepower. The aFe filter improved slightly (4 horsepower, from 570 to 574) on no filter, probably because of the radius at the transition from filter to outlet.

Later in that article, turbocharger sizing was discussed. This issue remains the biggest air-related concern for those who have added power and want better performance with lower EGTs. If you want to have your engine perform at a significantly higher power level and keep the exhaust gas temperatures within design limits for your engine (1300° degrees up to 2002 model year trucks, 1450° or 1500° for some Third Generation engines), choose your turbocharger wisely. Air box/filter selection will come naturally. But before spending \$500 on the air box, you are already at the point where you need to look at spending even more, but on the turbocharging system. Turbochargers have been discussed many times in the TDR, and some rational choices were covered in Issue 54, page 128, using the High Tech line as examples. The stock exhaust (turbine) housing was the greatest restriction in the exhaust system back in 1994, and remains so today. Go ask a drag racer about making 400 or 500 horsepower with one and a half inch diameter single exhaust. If you are lucky the guy will answer you and not call you something unpleasant. Yet, we are doing that with the stock exhaust housings. Pumping losses are significant even at stock power levels, particularly on Third Generation Turbo Diesels. Just a turbocharger change on an early '04 HO (305 rated horsepower) took the dyno power maximum from 280 to 306. Partly, a bigger compressor helped, but going from the stock 9 cm<sup>2</sup> exhaust housing to a 14 cm<sup>2</sup> housing (both were wastegated) made most of the difference.

Does more boost mean more power for our engines? With a given turbocharger (assuming non-wastegated) more boost does mean more power. Cheating the wastegate pressure setting, or swapping to a larger turbocharger negates the value of this old "rule-of-thumb." A '97 215 hp engine could make 207 hp at 24 psi or 37 psi with the stock turbo. It could make 280 hp at the same boost level (wastegated). It could make 565 hp at 36 psi with a larger turbo. Over 500 hp, the readings would be depressed if the air box and filter were too restrictive for the engine/turbocharger. At lower hp readings, no magic power increase was realized from a "better" air intake system because it really wasn't needed. So long as enough air was available, fuel was needed for power increases. Even today, lots of folks buy "more fuel" via boxes, injectors, etc. Then they try to forget about the super high exhaust temperatures that result if they did not "buy more air" at the same time. Buying air takes us back to the turbocharger first, sometimes the rest of the exhaust system, and more/cooler intake air flow.

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Dyno testing is important and effective, but there are a few limitations. First, the truck is not moving, so any ram air effect is missing and about all we can do is to open the hood and have a large cooling fan in front of the truck. Secondly, we need to know the level of reproducibility from run to run. Often 2, 5, or even 10 hp differences are solely due to inherent variability. More variability can be introduced, especially with high horsepower engines, as the engine gets heat-soaked after a few runs. You can seem to lose ten or twenty horsepower from your 500 or 600 hp engine when the cause was simply heat soaking. Dyno testing a high horsepower Turbo Diesel Ram is a delicate balancing act. You need the engine oil to be warm for the health of the turbocharger. You want the incoming fuel to be cool and dense. The air going into the engine needs to be warm enough for good combustion, but not so hot that density is needlessly sacrificed. Coolant temperature should be about 160° or so. These refinements aren't so important with stock engines or modestly uprated ones. They can become very important when the horsepower per cubic inch is high. These considerations become problematic with extended dyno testing of some air-related systems.

Not much, if any, difference will be seen with stock or near stock fueling, because "any" air intake system is pretty good. Only small effects on power are likely to be found with higher fueling levels, but the other causes of variability can be as large or larger than the actual effect that we are seeking to measure. Sometimes we think we have found a "gold mine" setup, when actually we only happened to get the other variables in our favor on that run. For example, the "before" run was the last of five runs, and the engine was heat soaked because those five runs were made back-to-back, not with one hour cool-down intervals between them. Now you spend two hours fitting a new system, and pick up 10 or 20 hp. Hmmm, was the new system great, or did the engine just cool enough to give a better run? Try five back-to-back runs to heat soak the engine again, and see what happens. Or, make every run after a cool-down period. And, on the other hand, how relevant to YOUR usage are the performance gains on a heat soaked engine (such as one that has towed a heavy trailer for a couple of hours), versus the gains for an engine with an "optimized" suite of temperatures for oil, coolant, fuel, etc.?

If the people testing some type of equipment really understand the variables and how to measure or control them, a good dyno can pinpoint a difference of a couple of horsepower. A very experienced and knowledgeable dyno operator and researcher (Lawrence Bolton) helped greatly. For example, I measured a difference of 4 hp at the 600 hp level with/without the stock fan. A once-popular electrical-clutch, temperature controlled aftermarket fan was touted as saving horsepower on our engines. The above 4 hp difference is a good measurement of the maximum power gain that could be expected, and on a high horsepower engine where that gain should be the highest. Not much gain could actually be expected for a system that cost around \$700, as I recall.

As another example, two different times I measured the difference from the highly popular high performance delivery valves on the 215 hp version of the P7100 injection pump. Both times I compared the stock, used valves (-181 part number) to brand new -191 "high flow" valves. The smoke increase was almost uncontrollable, so there must be more power—right? Nope, the dyno-verified difference both times was 0.00 hp. Another time, I tried the magic "cut" valves

with the retraction collar removed, on a high volume P7100. Oops, the engine LOST 12 hp compared to used -181 stock delivery valves. Without careful control of variables, these numbers could not have been measured accurately, and incorrect conclusions would most likely have been made.

**Joe Donnelly**  
**TDR Writer**

#### **Vendors/Suppliers and Manufacturers Mentioned**

##### **Advanced Flow Engineering (aFe)**

191 Granite St.  
Corona, CA 92879  
951-493-7100  
[www.aFeilters.com](http://www.aFeilters.com)

##### **ATS Diesel Performance**

5293 Ward Road  
Arvada, CO  
800-949-6002  
[www.atsdiesel.com](http://www.atsdiesel.com)

##### **Diesel Power Magazine**

[www.dieselpowermag.com](http://www.dieselpowermag.com)

##### **Performance Systems Mfg.**

17464 W. 43rd Drive  
Golden, CO 80403  
(303) 885-4418  
[www.psbuick.com](http://www.psbuick.com)

# Understanding Air Intake Systems – Part Two (Air Density)

ISSUE 59

## UNDERSTANDING AIR INTAKE SYSTEMS PART TWO (AIR DENSITY)

by Pete Tomka, Performance Systems Manufacturing

Part 1 on Understanding Air Intake Systems was in Issue 56, pages 150-156. That article discussed mass air flow and identified air flow resistance/pressure drop for various intake components and the resulting power gain/loss from these components. The article also recommended that any air intake should be tested “as installed” in the vehicle as a more practical approach in determining engine performance gains.

As a summary, a properly engineered aftermarket air intake kit installed on the Third Generation truck should produce rear wheel dynamometer power increases between 0-7 horsepower with stock fueling calibrations; between 8-11 horsepower with a 100 horsepower fueling module/tuner; and 17-20 horsepower with a 200 hp fueling module/tuner. The variations in power numbers reflect the year the truck was built and the type of fuel enhancement used. As you will see in this article, when you test a truck under real-world conditions, power improvements from most aftermarket intakes will diminish due to the effects of heat under the hood.

The owners of Second Generation trucks have a larger air box inlet opening, filter and intake tube diameter than the Third Generation trucks, resulting in even less power gains from an aftermarket intake kit. In fact, testing showed no power improvement from an aftermarket air box on a 390 horsepower truck. This supports Joe Donnelly’s statement that the stock air box is good for 500 horsepower. However, dyno testing did show a 2 to 3 hp gain when the Second Generation stock air box was modified for the PSM cowl duct.

Air density is a function of air pressure and air temperature. Air density can typically be increased by a drop in elevation and in air temperature. The only way you can modify air density is if you drive the truck to a lower or higher elevation, experience a variation in weather due to barometric pressure or temperature changes, or make changes to air flow components that lower intake temperature. This article will concentrate on the effects air temperature has on real-world engine performance.

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*Air density is a function of air pressure and air temperature. Air density can typically be increased by a drop in elevation and in air temperature.*

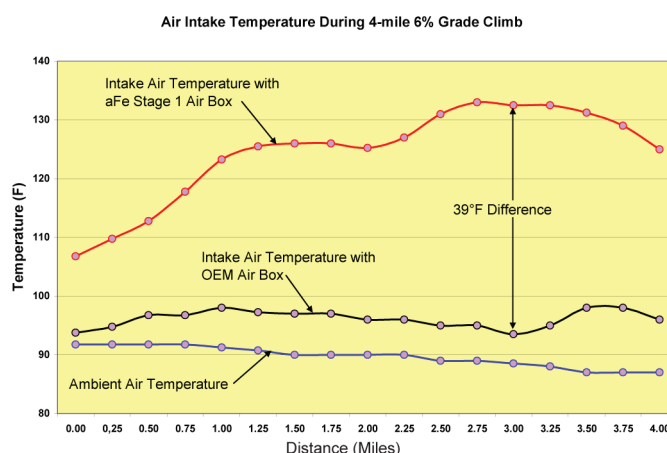
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## HOW AIR INTAKE TEMPERATURE EFFECTS POWER

Hot air rises because it weighs less than cold air. There are fewer air molecules in a given volume of hot air than the same volume of cold air. When the engine consumes hot air, there are less air molecules to burn with the fuel. This causes unburnt fuel to exit the combustion chamber, resulting in less power being produced. For every 5.5° rise in air intake temperature, engine power will be reduced by 1%.

Providing cold intake air to the turbocharger is also vital in making maximum boost pressure. How can you ensure the engine is getting the coldest air possible? Dodge uses a sealed air box that prevents hot engine compartment air from getting inside the engine. Most aftermarket air boxes are semi-opened which allows hot engine compartment air to reach the air filter. The differences in air intake temperature between these two types of air boxes can be dramatic when the engine is working hard. Graph 1 illustrates the difference in intake air temperature when a vehicle pulling a trailer with a GCWR of 17,000 pounds climbs a 6% grade for four miles.

The temperature charts used in this article were developed from real-world testing on a four-mile stretch of I-70 west of Denver, CO. The first 1.5 miles has a 6% grade, then the grade changes to 2% for the next .75-mile stretch before encountering another 6% grade for 1.5 miles. The last .25-miles is level. With the aFe air box, Graph 1 shows a sharp rise in intake air temperature when climbing those sections of the road with the 6% grade.



**Graph 1: aFe semi-open air box delivers up to 39° hotter intake air to the turbo than the OEM air box. Notice how intake air temperature increased with the aFe air box at the 2.5 mile point due to air flow components becoming heat soaked.**

From air density tables, the 39°F difference in air intake temperature (when using the aFe Stage 1 air box) will result in a 7% drop in density, which equates to a 7% horsepower loss (25 horsepower on a 350 horsepower truck). From the dynamometer tests in Part 1 of this article, the aFe air box produced 7 horsepower more than the OEM air box because of less air flow resistance in the aFe box. When considering air intake temperature differences, the drop in intake air density using the aFe box should cause the engine to produce 18 horsepower less than the OEM air box (25-7=18). This loss in power does not consider the effects of heat soaked air flow components, which will be addressed later in this article.

Looking at the graph you will notice a second steep rise in intake air temperature that occurs at the 2.5 mile point. At this point, the air flow components are now experiencing heat soaking. From previous air intake temperature testing, the aFe semi-opened air box allows 40% of the intake air to come from within the engine compartment. As the engine is working to pull the load up the grade, EGT will increase and the heat radiating from the exhaust manifold and turbo will cause the engine compartment air temperature to rise. As the test run continues, even hotter under hood air is ingested by the air filter. This cycle will continue until the driver backs off the throttle or crests the hill. Semi-opened heat-shielded type air boxes will cause the engine to keep losing power and road speed.

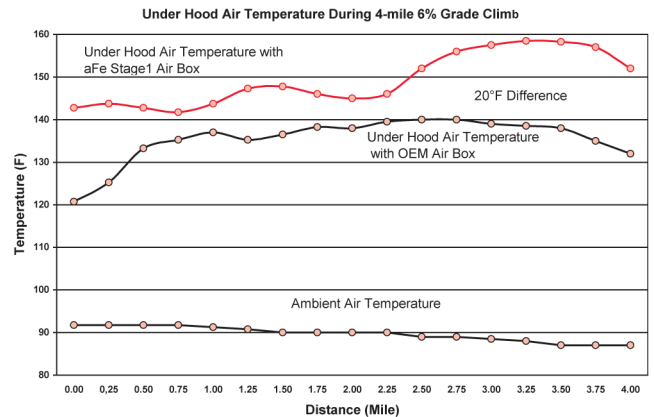
## HOW AIR INTAKE TEMPERATURE EFFECTS EGT

Is there any validity to the idea that cooler intake air results in cooler exhaust gas temperature? If so, how much? The 6% grade testing concluded that for every 1° of cooler intake air, the EGT is reduced by 1.5°. Mark Chapple at TST Products has performed similar testing and has determined that 1° of cooler intake air reduces EGT by 1.4°. John Holmes has also done testing and observed lower EGT while towing when colder intake air is consumed by the engine. Looking back at Graph 1, the semi-open type air box can raise intake air temperature 39° over the stock box and 46° above ambient air while the OEM air box raises intake air temperature by only 7°. Thus, EGT is affected by 55-59°.

## OTHER BENEFITS FROM COLD INTAKE AIR

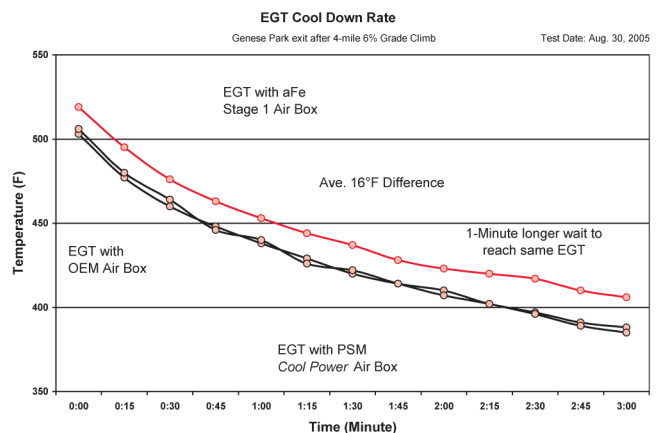
Increasing horsepower and lowering EGT are the two major benefits of using the OEM sealed air box. However, there are other benefits from cooler intake air.

- Increase fuel mileage: Rule of thumb is that every 10° drop in intake air temperature should increase fuel economy by 1%. This small mileage increase is impossible to accurately measure in real-world testing as there are larger variables that affect fuel mileage.
- Lower under hood temperature: The radiator, engine, exhaust manifold and turbocharger are the four largest contributors of under hood heat. Lower engine compartment temperature extends the life of plastic, rubber and electronic components under the hood.



**Graph 2: aFe semi-open air box generated up to 20° hotter under hood temperature than the OEM air box. Notice how under hood temperature with the aFe air box increased at 2.5 mile mark with air intake temperature rise from Graph 1.**

- Faster engine cool down: Since under hood air temperature is lower when using the OEM sealed air box, it stands to reason that the time it takes to cool the engine down to a pre-set temperature will be less. Tests indicate that the OEM box will get to a lower temperature at least one minute sooner than the aFe air box. See Graph 3.



**Graph 3: aFe semi-open air box had an average 16° higher EGT than the OEM air box during cool down. The aFe box took 1-minute longer engine idle time to reach the same OEM air box EGT.**

## DYNO POWER VERSUS REAL-WORLD POWER

The effect of rising intake air temperature and the detrimental effect this has on engine power in real world applications appears not to be a concern to air intake manufacturers. Most manufacturers do not advertise how much colder air their cold air intake kit delivers to the engine. Do they really know? Do they want to know? Or are they just concerned with improving air flow numbers on the flow bench!

Testing a vehicle on a dynamometer is similar to running a laboratory test, where environmental conditions and test procedures are optimized to produce the most power from the vehicle. Typically the hood is up to vent engine compartment heat away from the engine. Raising the hood may allow the air filter to be exposed

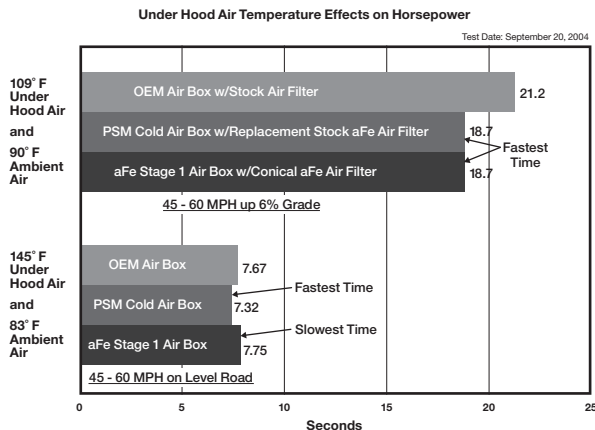
to cooler and less restrictive air above the filter. The engine is brought up to operating temperature just prior to the test run, and the turbocharger, intercooler and other engine components are given adequate time to cool down between runs.

Air flow performance products tested on a dynamometer will perform much differently on the street because of higher intake air and under hood air temperatures experienced in the driven vehicle. The effects from lower air density and heat from engine components that are run continuously, sometime at high loads for extended time periods, are difficult to account for on the dyno. It is not uncommon for an aftermarket air intake to make 7 to 10 more dyno horsepower than the OEM intake, only to make less than the OEM intake in heavy duty real-world racing, driving or towing situations.

The other point that needs to be made is that dynamometer variables and test procedures can be changed between tests to improve the power numbers. Any knowledgeable and experienced dyno operator can get from 5 to 10 more peak horsepower and up to 250 ft-lbs more torque by changing the test procedures. You can see these tricks being used in dyno graphs found in major diesel magazines. The writer or editors typically have no clue that they are being deceived. Consequently, it is the magazine readership that is given false information.

REAL-WORLD INTAKE AIR TEMPERATURE TESTING

During the development and testing of the PSM Third Generation cold air intake kit with an aFe Stage 1 air filter back in 2004, the test truck would accelerate with a 9000 pound trailer in tow faster than the OEM air box when the truck was just brought up to operating temperature. However, when the test truck and trailer were run in city traffic, and then immediately accelerated to highway speed, the acceleration was faster with the OEM air box. The only difference between these two real-world tests was the 36° difference in under hood temperature (109° versus 145°). The ambient air temperature was almost the same in both tests. This testing convinced PSM to stay with the OEM sealed air box and try to improve the performance of this box. See Graph 4.



Graph 4 - Acceleration Tests:  
OEM Air Box versus PSM Cold Air Box versus aFe Stage 1 Air box.  
The OEM air box accelerated truck and trailer quicker than the aFe air box when under hood air temperature increased.

DYNO TESTING FOR TEMPERATURE EFFECTS

If you could duplicate the rise in under hood temperature with the truck on the dynamometer, you could validate the approximate decrease in power one would experience in real-world driving.

With the use of ATS Diesel's Mustang Dynamometer, I tested the Second and Third Generation trucks to see what effects elevated under hood air temperature has on power. Vastly different power results were observed between the Second and Third Generation trucks when the hoods were closed.

SECOND GENERATION TEMPERATURE TESTS

This '99 Dodge test truck is owned by TDR member Betty Sutherland. Engine modifications include an ATS Aurora 2000 turbo, Arc-Flow intake elbow, Pulse-Flow exhaust manifold, 100 hp injectors and an Edge Comp fuel module. The air intake was stock.

| Hood Up<br>86° Intake Air |        |                                 | Hood Closed<br>135° Intake Air |         |
|---------------------------|--------|---------------------------------|--------------------------------|---------|
| HP                        | Torque | Air Intake                      | HP                             | Torque  |
| 391.5                     | 814    | OEM box w/aFe PG-7 filter       | No Data                        | No Data |
| 389.1                     | 799    | OEM box w/ side snorkel removed | 392.9                          | 808     |
| 393.9                     | 818    | OEM box w/ PSM cowl duct        | 396.3                          | 818     |
| 386.1                     | 798    | aFe PG-7 conical type filter    | 388.2                          | 796     |

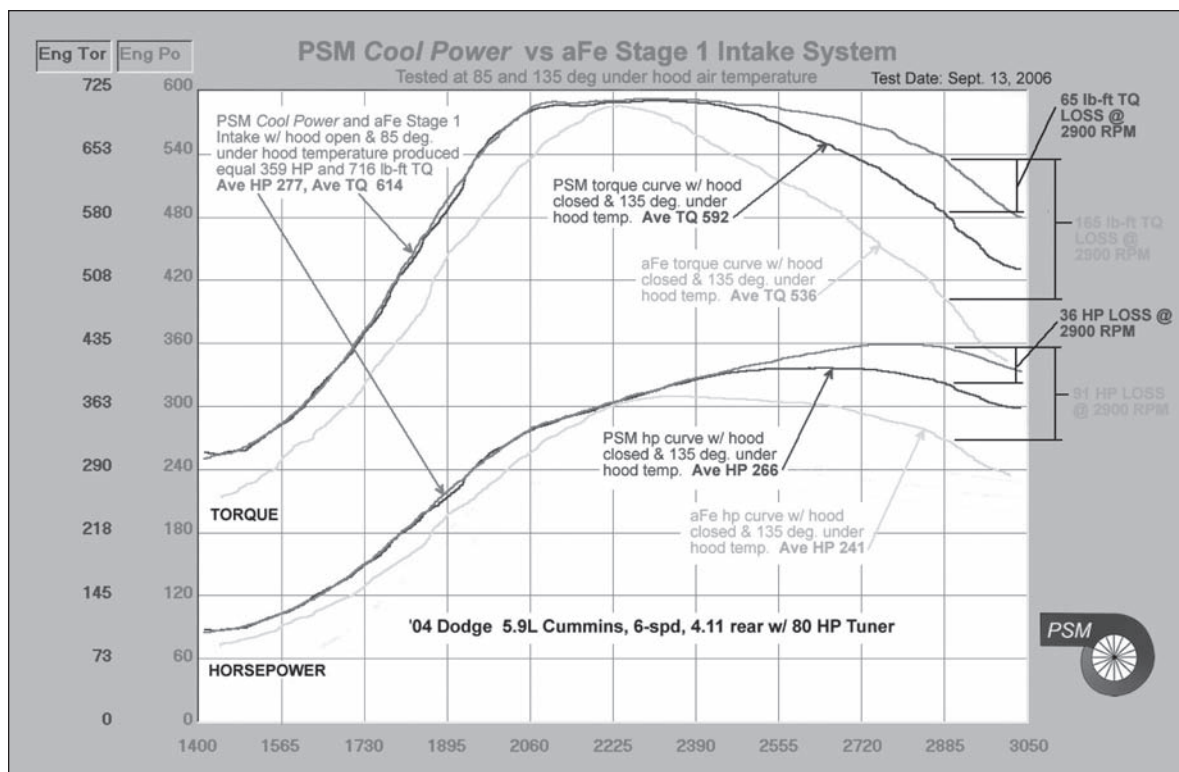
From the above tests we can conclude:

- 1) Removing the air snorkel between the air box and fender or using an open conical type filter resulted in lower power numbers because hot under hood air was allowed to enter the intake. This is true whether the hood was open or closed.
- 2) The engine made more horsepower with hotter under hood temperature and higher EGT. Hotter exhaust gases will drive the turbocharger faster, allowing the turbo to make more boost, resulting in increased engine power. Also, the Second Generation truck's ECM does not de-fuel the engine with a rise in air intake temperature.

THIRD GENERATION TEMPERATURE TESTS

The air filters used in this test are an open aFe air intake (54-10411) and an Afe Proguard 7 drop-in, panel-type filter (73-10102) with the PSM cold air box.

Both intakes made identical power with the hood open in 85°F engine compartment air. A series of tests were run on the two intakes with the hood open and then with the hood closed in 135°F engine compartment air. The power numbers for these runs are shown on the graph on the following page.



The top series of lines represents torque and the lower series is horsepower for the four different tests. With the hood up, both the aFe and PSM air boxes made identical 359 horsepower and 716 lb-ft torque. These two tests are shown as a single line and represent the top line of the torque and horsepower curves. With the hood closed, the power produced using the PSM air box is shown as the middle curve, and the aFe air box power is shown on the lower curve of the torque and horsepower graph.

The power produced from the PSM air box when under hood temperatures were 135°F was identical to the open hood test until 2325 rpm when the air temperature recorded inside the intake manifold began to rise as the intercooler became heat soaked. This caused the intake air to become less dense. The MAP/temperature sensor in the intake manifold relayed this information to the ECM, which began to de-fuel the engine to compensate for the loss in air density. At 2900 rpm, the engine lost 65 ft-lbs torque and 36 horsepower when compared to the open hood test. Average horsepower was down 11 hp and the average torque was down 22 lb-ft when compared to the open hood test.

The power produced from the aFe air box was down at the start of the run by 12 hp when the hood was closed and under hood temperature reached 135°F. This loss in power is directly related to the loss in air density as a portion of the hot air was already inside the air box at the start of the run. Once 2250 rpm was reached, power began to drop off at a much faster rate as the intercooler became heat soaked much sooner and the ECM pulled more fuel out of the cylinders to compensate for the faster loss in air density. At 2900 rpm, the aFe air box caused the engine to lose 165 lb-ft torque and 90 horsepower compared to the open hood test. Average horsepower was down 36 hp and the average torque was down 78 lb-ft when compared to the open hood test.

The net effect is that the aFe air box made 55 less horsepower and 100 lb-ft less torque at 2900 rpm than the PSM air box when tested on a dyno that simulated real-world under hood air temperature. This dyno test confirms why the PSM and OEM air box out-accelerated the aFe box on the street (Graph 4) when under hood temperatures were 145°F.

### PSM's PROVEN COMBINATION

The ideal air intake strikes a balance between reducing air flow restriction and providing the coldest air to the engine. Part 1 showed that improvements could be made to the OEM air box that would equal the power gain from an aFe semi-opened box when tested under ideal dyno conditions. Part 2 has shown that the OEM sealed air box provides colder air to the engine for more power than a semi-opened, heat-shield type air box.

The OEM air box is the best sealed air box available to date, but it has one weakness: insufficient opening area in the side of the box to feed the engine all the cold air it needs for maximum power and lower EGT. The PSM cold air intake solves this shortcoming with a flexible duct that picks up cold air from under the truck and delivers this air to the OEM box. Further power improvement and lower EGT can be made by the use of DPP silicone rubber *Cool Hose* intake tube, which provides colder air to the turbocharger than any other aftermarket intake tube tested. With the use of an aFe Pro-Guard 7 air filter, PSM calls this air intake their "proven combination" and guarantees this system will provide more cold air to the engine than any other air intake.

## HOME BUILT AIR INTAKES

Many Turbo Diesel enthusiasts are constructing their own cold air intake using the same principle as the PSM system. However, they are missing one important air flow component that directs air into the duct. Understanding air flow is not as easy as it looks.

## NEW STOCK REPLACEMENT CONICAL AIR FILTER

Air filter manufacturers are now producing a conical type filter that drops into the OEM air box. Conical filters are known to have more surface area for increased air filtration and lower air flow restrictions than OEM flat panel type filters. Flow bench testing these filters without the air box does result in less pressure drop than the flat panel filter. However, once a conical type filter is installed in the stock air box, the air flow restriction significantly increases. Most aftermarket intakes that use a conical type filter have insufficient air space between the filter and the sides of the box. This is why manufacturers remove one or more sides of the air box, which then exposes the air filter to hot engine compartment air. They solved one problem by creating another more serious problem!

## AFTERMARKET SEALED AIR BOXES

Manufacturers are beginning to offer fully enclosed sealed air boxes to keep hot under hood air out of the air intake. They are also making claims that their sealed boxes provide colder intake air to the engine than the OEM box. Customers should closely examine how these manufacturers are sealing the space between their air box and the OEM plastic fender inlet. The factory uses a tight fitting foam seal on all four sides of this inlet which stops the hot under hood air from getting inside the box. Some manufacturers have a rubber seal on two sides of their inlet and others use no seals. Be aware that air boxes constructed from metal will conduct heat into the air intake faster than the OEM plastic box. Some manufacturers are now bringing in additional air from a scoop or short duct located just under the air box. PSM testing revealed the air inlet needs to be a minimum of 16 inches below the air box to prevent engine compartment air from entering the inlet.

## SUMMARY

- Every 5.5°F increase in air intake temperature reduces engine power by 1%.
- Every 1°F of cooler intake air will reduce EGT by approximately 1.5°F.
- Cooler intake air reduces under hood temperature.
- OEM sealed air box allows the engine to cool down faster than semi-open heat shield type air boxes.
- Cooler intake air improves mileage. Every 10°F drop in intake air increases mileage by 1%.
- The OEM sealed air box provides the coldest air to the engine. Semi-open heat shield type air boxes in real-world driving conditions allow hot engine compartment air to enter the intake.

- Second Generation trucks do not de-fuel with a rise in air intake temperature like the Third Generation trucks.
- On Third Generation trucks, power numbers from a chassis dynamometer are much lower in real-world driving due to under hood heat generated from the radiator, engine, exhaust manifold, turbocharger and heat soaking of the intercooler.
- In real-world acceleration tests on Third Generation trucks, the OEM sealed air box allows the truck to accelerate faster than the aFe Stage 1 semi-open air box when engine compartment temperatures are within normal (120 to 140°F) operating range in 80 to 90°F ambient air. With low engine compartment temperatures, the aFe air box allowed the truck to accelerate faster than the OEM air box.
- On the Third Generation trucks, intake air temperature has a much larger effect on engine power than lowering air flow restriction within the air intake. A low air flow restriction intake can make more than 10 horsepower above the OEM air box. However if engine compartment air is getting inside the intake air box, the engine can lose up to 50 horsepower more than with the OEM air box.
- The new conical drop-in type stock replacement filters have a higher air flow restriction than the OEM air filter.

**Pete Tomka**  
**Performance Systems Mfg.**

## Vendors/Suppliers and Manufacturers Mentioned

**Advanced Flow Engineering (aFe)**  
191 Granite St.  
Corona, CA 92879  
951-493-7100  
[www.aFefilters.com](http://www.aFefilters.com)

**ATS Diesel Performance**  
5293 Ward Road  
Arvada, CO  
|800-949-6002  
[www.atsdiesel.com](http://www.atsdiesel.com)

**Diesel Power Products**  
4302 E. Congress Ave  
Spokane, WA 99223  
866-379-8685  
[www.dieselpowerproducts](http://www.dieselpowerproducts)

**Performance Systems Mfg.**  
17464 W. 43rd Drive  
Golden, CO 80403  
(303) 885-4418  
[www.psmbuick.com](http://www.psmbuick.com)

# Third Generation Purchase Criteria

ISSUE 77

## WISH I'D KNOWN THAT (Buying a 2003-2009 third Generation Truck)

TDR members are very good at holding on to their old magazines. Likewise they know that indexes of previous articles were published yearly until year 2009. These important archives were compiled by Bob and Jeannette Vallier. These valuable yearly indexes are found in Issues 65, 61, 57, 53, 49, (deduct 4), etc. Then in 2009, we implemented a digital search of TDR magazines back to Issue 40 at our web site.

So, a solid infrastructure exists for those who want to research a topic.

But, how about a resource for those folks who don't know what they don't know?

That's right, something for the "wish I'd known that" crowd.

Wait a minute, isn't that what the TDR's Turbo Diesel Buyer's Guide (TDBG) is all about? Yes, indeed, and there is so much detail (aka, TDR's solid infrastructure) in the TDBG – Oops, perhaps the detailed research is too daunting of a task for the prospective new owner who doesn't know what he doesn't know. How can we keep it simple?

Easy. I gave the "Wish I'd Known That" assignment to Joe Donnelly for the First Generation truck, Scott Dalglish for the Second Generation truck and I took the Third Generation truck. I created an outline for each of us to follow and I completed the assignment first so they could see how the format should be turned into entertaining and educational text.

## The Outline

Rather than reinvent the wheel, I used the established categories used by the Chrysler group for all of their Technical Service Bulletins. That numerical system is as follows:

|                              |                                  |
|------------------------------|----------------------------------|
| 2 Front Suspension           | 14 Fuel                          |
| 3 Axle/Driveline             | 16 Propeller Shafts and U-Joints |
| 5 Brakes                     | 18 Vehicle Performance           |
| 6 Clutch/Manual Transmission | 19 Steering                      |
| 7 Cooling                    | 21 Automatic Transmission        |
| 8 Electrical                 | 22 Wheels and tires              |
| 9 Engine                     | 23 Body                          |
| 11 Exhaust/Air Intake        | 24 Air Conditioning              |
| 13 Frame and bumpers         | 25 Emissions Control             |
|                              | 26 Miscellaneous                 |

Within each of these categories I will present the most common "Wish I'd Known That" problems that have been encountered by the TDR audience. Then I'll give a brief write-up of the solution with a TDR reference location (perhaps within the TDBG, perhaps in the magazines) where the new or prospective owner can go for details as needed. Here goes...

## General Information

Before I start my "Known That" story, I'll remind you of an inspection chart that TDR writer Andy Redmond uses for evaluation of any used vehicle. The detailed chart is found in Issue 70, page 121.

If you use this level of detail in your pre-purchase exercise(s), I have no doubt that the seller will be impressed with the thoroughness of your vehicle search. Andy's inspection list trumps my, "If the door jams and truck seal (or tailgate lift area) are clean, I am a buyer" pre-purchase criteria.

Rather than bore you with the "do a Carfax Report; check the NADA and Kelly blue book values; check with your insurance agent for policy prices; loan values; etc.," I'm going to make the assumption that this truck purchase is not your first rodeo. If you need further information:

TDBG, "Buying a Used Truck"

TDR #70, page 120, "Pre-Owned Purchase"

TDR #73, page 96, "Let the Search Begin"

This issue, page 80, "The Search for a New Ram"

Likewise, the TDBG is a fantastic source for performance and miles-per-gallon enhancements; specifications; Technical Service Bulletins; yearly changes to the truck; evolution of the different Cummins engines; warranty considerations – wait, why not give you the table of contents because I can guarantee it will be referenced when I get into the "Known That" story detail. The TOC is on the next page.

|                                                                                                            |            |
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| <b>Evolution of the Cummins Engine,</b><br><b>1989-Current.</b> .....                                      | <b>26</b>  |
| <b>Performance Enhancements,</b><br><b>1989-Current.</b> .....                                             | <b>48</b>  |
| <b>Performance, Warranty and You</b> .....                                                                 | <b>70</b>  |
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| <b>Why Didn't They Think of That –</b><br><b>Exhaust Emissions.</b> .....                                  | <b>83</b>  |
| <b>So You Want Fuel Economy.</b> .....                                                                     | <b>89</b>  |
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That, my friends, was a heck of a long introduction. Those with an eye for the details will carefully examine the [TDBG's](#) "TSBs Issued During '03-'09," pages 182-205. These documents give the service network the proper repair technique for the most common Third Generation truck problems. Perhaps this article should have been simply republishing those 23 pages?

No, let's attempt the highlights and add additional commentary. Here goes: Now, for the data that you've been waiting for, "Wish I'd Known That – Third Generation, 2003-2009."

## 2 Front Suspension

For this concrete-cowboy who lives in Atlanta, Georgia, there is no need for a four-wheel drive truck. With the two Third Generation trucks that I have owned (one is still in the family) I can say that the only suspension maintenance required was to change the shock absorbers at 175,000 miles.

In consulting with my four-wheel drive buddies, they tell me that the Third Generation's suspension is greatly improved over that of the previous '94-'02 Second Generation truck. However, if you add big wheels and tires, raise the suspension and/or exceed the 100,000 milestone you will have to go underneath the truck and monitor the suspension components for wear. While this generation of truck is not as prone to the "death wobble," the aforementioned big tires/raised suspension/mileage will have the owner looking at beefing up the steering box stabilizer, track bar, track bar bushings and steering damper. Unfortunately, there is not a one-size-fits-all solution to suspension wear. There is a 10-page article in the [TDBG](#) that covers suspension inspection and alignment specifications, pages 235-245.

## 3 Axle/Driveline

One word: bulletproof. Certainly there have been individual problems, but when was the last time you read a TDR article about U-joints, drive shaft, transfer case or axle problems?

## 5 Brakes

Normal maintenance is required.

If you want a complete tutorial on brakes, brake pads, brake bias, etc., you'll want to review the four-part series written by brake expert, James Walker, in TDR Issues 40-44. Yes, this is the same James Walker that authored the book [High-Performance Brake Systems](#). His words from Issues 40-44 still hold true today.

Issue 40: James explains that your brakes do not stop the vehicle.

The traction available between the road and the tire's four contact patches are what stops the vehicle. With this bit of enlightenment, you can bet that Issue 40 is worth a reread as James covers "Braking Systems in Plain English." Discussion about everything from the brake pedal, master cylinder, brake calipers, brake rotors, brake pads, brake lines are in the Issue 40 text.

Issue 41: "Brake Pad Selection." Brake pad material is a compromise. Read all about it.

Issue 42: "Twenty-One Brake Questions." From how to break in brake pads to why the rotors warp, James answers your 21 questions.

Issue 43: "Brake Fluid." What is the difference between DOT 3, 4, 5 and 5.1? You'll know after you reread Issue 43.

Issue 44: "Brake Bias." Have you ever locked up the rear tires and have the back of the vehicle want to pass the front? Do you know more about brake bias than the factory engineer? Another James Walker article that is worthy of reread.

## 6 Clutch/Manual Transmission

**Transmission Options:** You know, the TDBG is an excellent reference guide—I had to refer to its section "Looking at the Changes," pages 14-19 to see what clutch/gearbox was used in the different '03-'09 Third Generation trucks. Here goes—

2003: NV4500 with standard 235 or 250hp engine  
NV5600 with high output 305hp engine

2004: Early 2004 models in CA, ME, MA, NY and VT got the NV4500 gearbox with a 235hp engine. All other states got the NV5600 gearbox with a 305hp engine

2004.5: A mid-year introduction gave all states the 325hp engine and a NV5600 gearbox.

2005: As the 2005 model year progressed, the New Venture NV5600, six-speed manual was replaced by a Mercedes Benz designed G56 six-speed manual transmission. The reason for the change: New Venture Gear was a joint venture company between DaimlerChrysler and GM. In December of 2002 the partnership was dissolved and New Venture was/is wholly owned by GM.

So if you have a 2005 truck with a six-speed transmission, how do you tell—without crawling under the truck looking for signs of identification—if it is the NV5600 or the G56? Easy, the shift pattern for a NV gearbox has reverse up and to the right; the G56's pattern is over to the left and down. (Thanks, Peter Pyfer at South Bend Clutch.)

2006: The G56 Mercedes Benz is now the only manual transmission that is offered.

2007: Same

2007.5-2009: In early 2007 the internal ratios of the G56 transmission were revised. The new gearbox is given the name "G56R." The following is the comparison chart.

|             |      | 1    | 2    | 3    | 4    | 5    | 6   |
|-------------|------|------|------|------|------|------|-----|
| '05-'07     | G56  | 6.26 | 3.48 | 2.10 | 1.38 | 1.00 | .79 |
| '07.5-newer | G56R | 5.94 | 3.28 | 1.98 | 1.31 | 1.00 | .74 |

**Clutch Discussion:** All clutches are a compromise. For the most part, if you drive the truck as it was intended and do not increase the engine's performance, the clutches used in Third Generation trucks give the owner acceptable (and then some) life. So, in an effort to write an article for "Wish I'd Known That," there is not a beware-of-this statement that has to be addressed.

The clutch used with the NV4500 and NV5600 was mated to a single flywheel.

The clutch used with the G56 and G56R is mated to a dual mass flywheel.

If your truck has a clutch problem; if you want to learn more about clutch replacement options; if you need to learn more about the dual mass flywheel and flywheel options for your G56/G56R, here are the related articles in the TDR that will help you.

| Issue | Page(s) | Title                              | Author       |
|-------|---------|------------------------------------|--------------|
| 30    | 36-39   | NV4500 Drivetrain Updates          | Joe Donnelly |
| 31    | 28-29   | Manual Clutches for the NV5600     | Joe Donnelly |
| 38    | 140-141 | Troubleshooting Short Clutch Life, | Peter Pyfer  |
| 55    | 58-59   | Clutches 101                       | Jim Anderson |
| 63    | 40-44   | Covering the Basics                | Gary Croyle  |
| 66    | 94-101  | Turbo Diesel Clutch History        | Joe Donnelly |
| 67    | 78-79   | Performance Clutches               | Joe Donnelly |
| 68    | 88-90   | Dual Mass Conversion and the G56   | Joe Donnelly |
| 71    | 12-16   | Dual Disc Clutch for the NV5600    | Doug Leno    |
| 72    | 10-12   | Dual Disc Clutch Update            | Doug Leno    |

**Gearbox Discussion:** As I mentioned in the Clutch discussion, in writing for the "Wish I'd Known That" audience there is not a beware-of-this statement about gearboxes used in the Third Generation trucks that has to be addressed. And, just like the clutch discussion, the TDR's writers and members have "been there, done that" with the gearboxes. How so? Well, take a look at the reference material listing that I have provided below:

| Issue | Page(s) | Title                          | Author          |
|-------|---------|--------------------------------|-----------------|
| 53    | 94-98   | G56 and the Dual Mass Flywheel | Scott Dalgleish |
| 53    | 98-101  | G56 compared to NV5600         | Scott Dalgeish  |
| 64    | 85-89   | Rebuilding the NV5600          | Joe Donnelly    |
| 67    | 84      | Rebuilding the NV5600          | Joe Donnelly    |
| 68    | 88      | G56 Rebuild                    | Joe Donnelly    |
| 70    | 12      | NV4500 Repair                  | Joe Donnelly    |
| 71    | 106-109 | G56 Rebuild                    | Joe Donnelly    |
| 75    | 92-94   | Manual Transmission Review     | Joe Donnelly    |

---

Pay particular attention to Donnelly's Issue 75 article (pages 92-94) and the "Backfire" discussion on pages 106-107, as the text gives you some preventive maintenance and accessory tips:

To summarize, the articles recommend: G56 and NV5600 – The addition of transmission coolers, for cooling and for extra lubricant capacity, is a good idea. Likewise, do not "over-torque" the gearbox by leaving it in sixth gear/low rpm when you encounter steep terrain.

G56 – ATF+4 is the recommended lubricant. Donnelly and transmission vendors recommend over-filling the G56 by one quart and using a heavier fluid (Pennzoil Synchronesh as used in the NV5600 or a GL6-rated lubricant).

## 7 Cooling

Normal maintenance is required.

The [TDBG](#) has a summary of all of our antifreeze discussion on page 295.

And, for anyone who has had to change a water pump on any vehicle other than their Turbo Diesel, you have to give the Cummins engineers credit for the super-simple water pump design. Remove the accessory drive belt, remove two 10mm bolts that hold the water pump in place and you've got this project close to completion. Cooling system problems are few and far between.

## 8 Electrical

Normal maintenance to the alternator, starter, batteries, solenoids, etc., is required.

In this issue, you'll read about Chrysler's totally integrated power module (TIPM) that controls many of the truck's electrical functions. A replacement TIPM is expensive (\$700) and now that these trucks have aged—and seen multiple owners with multiple trailers with who-knows-what wiring—we are seeing TIPM failures. The TIPM was not designed as a circuit breaker, and, if owners do not correct wiring problems, they find out how expensive it is to replace the TIPM if they use it as a circuit breaker. Ouch.

## 9 Engine

With all of the components that make up an engine, you would think that there would be a long list to discuss. However, aside from programming issues with the 6.7-liter engine (covered later in "Vehicle Performance"), the 5.9 and the 6.7 are rock solid! And, in fact, the '03-'07 5.9-liter engine is regarded by Turbo Diesel enthusiasts as the best of all. It is easy to maintain and service. The valve adjustment is every 100K miles. Hot rod parts are inexpensive and abundant and 400 horsepower is easy to attain. (Over 400 gets expensive as turbochargers need to be modified and other components have to be matched to the higher engine output.) Also, fuel mileage can be improved. All the particulars are in the [TDBG](#) starting on page 48 and again on page 89.

As I mentioned in "Axle/Driveline," there are always individual problems that occur, but when was the last time you read a TDR article about a bad turbocharger, water pump, oil cooler, oil pump, camshaft, valve train, etc.?

However, there is one area of the engine that is prone to wear. To meet emissions standards the engine uses a Bosch high pressure common rail (HPCR) fuel injection system. These injectors can fire as many as four times in a combustion event. Fuel filter maintenance (every 15,000 miles) and clean fuel are paramount to injector life. The average life span is 160-200,000 miles. Normally, if you need to replace one injector you'll need to replace all six—kind of like the purchase of replacement tires. Expect to pay \$350-400 per injector or \$2100-\$2400.

TDR writer Joe Donnelly tried to capture everything you need to know about the HPCR injectors in his Issue 72 article "Injectors for HPCR Engines." The three page article starts on page 44. Any owner who wants to understand the principle of operation; wants to understand the importance of clean fuel; needs to replace an injector; has an engine stumble; wants to know about performance injectors; wants to know about alternate fuels; etc., you'll want to reread Joe's article. It is as relevant today as it was one year ago. Again, that is Issue 72, pages 44-57.

Performance upgrades for the 5.9-liter engine: Read all about it in the [TDBG](#), pages 89-112, "So You Want Fuel Economy."

Performance upgrades for the 6.7-liter engine: Three words sum it up—don't do it. The [TDBG](#), pages 70-75, "Performance, Warranty and You," gives you the reasons. Also, flip to page 56 and read "Section 18 – Vehicle Performance" for the reason(s) that I suggest you leave the 6.7-liter engine alone.

## 11 Exhaust/Air Intake

I just returned from a show where the proud Turbo Diesel owner told me about his '06 truck with the free flow exhaust, super monster filter and powder-coated intake air horn. He told me about the increased mileage (Really?) and the fact that he could hear the difference (No doubt!).

After we touched on several other topics—my favorite was the biodiesel junk—it was obvious that any challenge that I might present that opposed the justification for his modifications would be futile. So, I found a reason to excuse myself and walked away.

Don't get me wrong. In the quest for high horsepower, performance exhaust and intake systems have their place. Both work to lower and control exhaust gas temperatures and give a measure of better horsepower. However, with the exhaust system you sacrifice noise, with air intakes you may sacrifice air filtration.

So, for the guy who wants a dependable, reliable truck, my suggestion is to leave the exhaust and air intake alone.

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This is especially true with the 6.7-liter engine. Our contacts at Dodge tell us that the new emissions laws require more sensors than ever before. The engine is very sensitive to intake air temperature and any change in the filter or airbox could lead to:

- The potential for too much hot underhood air which can cause a derate condition. This occurs most often in high altitude situations when the engine fan is engaged.
- Too much oxygen (O<sub>2</sub>) in the exhaust system. This can prevent the regeneration from coming on and foul the exhaust aftertreatment system.

For 5.9-liter owners the K&N filter debacle was covered in Issue 34, pages 105. Back in the Fall of 2001 Cummins tested the K&N for air flow and dirt flow. The result: Yes, they flow more air *and* more dirt. At the time the K&N was the number two selling item at the sister company Geno's Garage. As much as it could have hurt sales, the folks at Geno's pulled the item from the shelves and no longer offer the K&N line of filters.

Finally, the air filter, cold air intake, and the performance you should expect from these types of modifications was covered in Issue 56 and 59. These articles are also conveniently found at the Geno's Garage web site under "Technical Information" and then the title "Understanding Air Intake Systems," or at the TDR's web site in the digital back issues area.

### 13 Frame and Bumpers

Back in 2003 Dodge introduced a new-and-improved hydroformed frame. This manufacturing technique results in a stiffer and stronger frame.

The folks at Dodge did not want a bunch of owners and aftermarket installers messing up this frame with Swiss cheese-type holes. They issued a technical service bulletin (TSB 13-001-03, 2/7/03) that set forth their guidelines. Since these trucks are now ten years old, I've no doubt that the second and third generation owners have ignored the TSB and the Swiss cheese holes have been drilled. The take away: beware of the overzealous frame driller. Aside from this watchword, the frame and bumpers are not problem areas.

### 14 Fuel

As mentioned in "Section 9 Engine Discussion," clean fuel is paramount to injector life. In this issue see pages 14 to 16 for more information on clean fuel (Chrysler TSB 14-004-11).

Biodiesel: With the cost of injectors at \$2100-\$2400 per set (and the other HPCR injection components aren't cheap either) I would steer clear of unknown biodiesel and not use anything greater than a B20 blend from a reputable supplier. Your Owner's Manual states that you should only use a B5 blend.

### 16 Propeller Shafts and U-Joints

Normal maintenance and inspection are required.

### 18 Vehicle Performance

For ease of reading I will break this topic into the two engines used in Third Generation trucks: the 5.9-liter and the 6.7-liter.

### 5.9-Liter Engine



Earlier I mentioned that the 5.9-liter from '03-'07 is regarded as the best of all engines found in our turbo Diesels. Leave it stock and it will last forever.

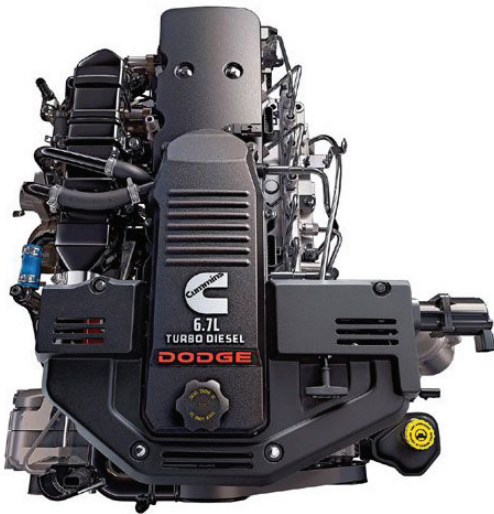
However, "leave it stock" is not a statement that the typical Turbo Diesel enthusiast can abide. So, what do owners do to this engine in their quest to improve on what was provided by the Cummins factory folks?

Boy, this is a lengthy topic. Exhaust and air intake have already been discussed in category 11. Programmers, turbochargers, camshafts, hot-rod injector—the TDR's writers have "been there, done that" and achieved some amazing results with horsepower *and* fuel economy. I'm not going into all of the details for this "Wish I'd Known That" article, but I will give you the chapter and verse so that you can do due diligence in your research—[TDBG](#), pages 89-112, "So You Want Fuel Economy" with particular attention to pages 97 and 108. Scott Dalgleish articles: Issues 50, 51, 52, 54, 59, and 61. Doug Leno articles: Issues 45, 47, 48, 49, 51, 53, and 57. Doug Leno article update: Issue 68, pages 50-57.

Now, while you are on your due-diligence quest for horsepower and economy you need to realize that, for the most part, *none* of the performance gains were done using aftermarket parts that meet any EPA or California Air Research Board (CARB) emissions standards or testing. You are reading between the lines correctly: Prior to 2007.5 (actually 2009, but it is a real long story\*), the world of diesel performance aftermarket parts was like the wild, wild West—anything, everything and lots of black smoke.

\*If you want the long story, you'll have to attend the Specialty Equipment Manufacturer's Association (SEMA) show each year and sit in on the diesel performance roundtable discussions. A summary of many years of my participation is found in the [TDBG](#), "Performance Warranty and You," pages 70-75. Before you add any winky-twinky performance items to your truck, you need to understand the potential \$25,000 fine you could face for violation of EPA code 203(a). Ouch!

## 6.7-Liter Engine



As mentioned, the vehicle performance section was broken into two categories. Now it is time to discuss the 6.7-liter engine from the '07.5-'09 model years.

TDR members know that some of the odd model year designations ('91.5, '98.5, '07.5) coincide with the tightening of federal exhaust emissions rules. Such was the case with the 6.7-liter introduction as an '07.5 model. And, if you recall from your reading in the TDR or from the [TDBG](#), the 6.7-liter engine was a step ahead of the competition and the federal emissions standards as it was emissions compliant for the standards that would be in force in 2010. Detailed information about the hardware changes that coincided with the 6.7-liter introduction: [TDBG](#) pages 40-46, "The 6.7-Liter Engine Introduction."

Yet, early to the market with the new technology does not always equate to seamless reliability. Notice I did not mention durability, as the hardware (block, cylinder head, turbo, EGR components, water pumps, fuel injection equipment, etc.) have not given owners undue problems. However, the software, i.e., programming of the engine to stay in-sync with the emissions control hardware (the diesel particulate filter, the EGR controls, the diesel oxidation catalyst and the nitrogen absorber catalyst), has caused owners their share of grief. Knowing that there are two sides to every story, the blame is not entirely that of Cummins and Dodge. Back in '07.5 we still had folks purchasing diesel trucks without a need to really have a diesel. The 6.7-liter engine should not be used to drive around town and bring home groceries.

Time has proven that if you use the engine as intended and leave it stock, it will last forever. This statement is a repeat of my assessment of the '03-'07 5.9-liter engine. However, unlike the 5.9 owner that could not resist modifying his engine, the 6.7-liter owner had better leave it stock.

For those that resisted the temptation to tinker, in the past four years the 6.7 owner was faced with multiple ECM flashes and updates. Often these updates were complicated by fraudulent owners that would pull their hot-rod programmer off the truck or reflash the ECM to stock. In March 2009, the Cummins folks—perhaps tired of this illegal game, and wanting tighter control of their ECM and/or influence by the EPA to stop owner tampering—embedded software to make sure only approved calibrations were downloaded, a secured ECM. If a non-approved flash was detected, a trouble code U1601 was set and the engine would not start.

Looking back to the TDR's coverage of the secured ECM (Issue 67, page 34, "Spy Versus Spy: The 3/2009 Secured ECM") I did some research to see how successful Cummins has been with their security attempt. Since there are aftermarket products available for Turbo Diesels made *after* 3/2009, one has to assume that the aftermarket folks found a way around the U1601 code and that engines do start with the aftermarket programmers. However, in typical Spy versus Spy fashion, I've no doubt that there are other counters (the number of downloads), timers or red flags in the ECM to tell the Dodge service technician that a reprogram has occurred.

If you value your warranty status, how many times do I have to say "Leave the engine stock."

Here is what to look for if you play hot-rod guy with the 6.7 engine: First off, admit that you are a cowboy, a one-percenter, a member of the lone-wolf club. It is now *your* engine, and you are your own warranty station! Next, please read the [TDBG](#) article "Performance Warranty and You," pages 70-75. Subsequently, the EPA and CARB have made enough threats to keep many in the aftermarket from playing in the 6.7-liter performance business. Likewise, another deterrent is the 2010 CARB emissions test that California residents have to pass in order to get a license tag.

Now, after all of the cautions that I have presented, I can only imagine that there will still be owners that want more performance from the 6.7-liter engine. In Issue 67, pages 31-34, I listed all of the modules/programmers that were available for the engine. In conclusion, I wonder to myself, "How many different ways can I say leave the engine stock."

Finally, the TDR followed the trials and tribulations of a member that modified his 6.7-liter engine in a short article in Issue 72, page 32: "The Long Story, a Tale of Woe."

Regardless of the cautions that I've issued, there will be the instance where a fault code/check engine light appears on your dash. How do you read the code and what does it mean? Is the code a nuisance or a serious call to action? Again, the intent is to keep this article brief: you can find all of the fault code answers in Issues 74, pages 84-85; Issue 66, pages 90-91; and the [TDBG](#), pages 269-278.

## 19 Steering

In my review of the TSBs from '03-'09 ([TDBG](#), pages 182-205) I did not see anything out of the ordinary in the steering category.

21 Automatic Transmission

In my review of the TSBs from '03-'09 (TDBG, pages 182-205) I did not see anything out of the ordinary in the automatic transmission category.

Before you cry, "Foul, we know there are automatic transmission problems," let's try for a civil discussion on the topic.

First, let's discuss the time frame for changes to the automatic transmission. The first big change was January 1, 2003, for the change from the 47RE to the 48RE. There were no internal gear ratio changes.

The next change was January 1, 2007, for the change from the 48RE to the six-speed 68RFE. The new 68RFE went hand-in-hand with the '07.5 introduction of the 6.7-liter engine. The gear ratio comparison to the 48RE:

|             |       | 1    | 2    | 3    | 4    | 5   | 6   |
|-------------|-------|------|------|------|------|-----|-----|
| '3.55-'07   | 48RE  | 2.45 | 1.45 | 1.0  | .69  |     |     |
| '07.5-newer | 68RFE | 3.23 | 1.84 | 1.41 | 1.00 | .82 | .68 |

The complete "Ask the Engineer" story about the 68RFE is found in TDR Issue 58, pages 46-47.

Now, let's talk reliability, durability and all that stuff...

Okay, the '03 and '04 models have the same throttle position sensor (TPS) as the '98.5-'02 trucks. The TPS has been widely known to give folks problems. Do you need to do some research to find out the particulars? TDBG, "Vintage '94-'02 Lock/Unlock," page 23.

More reliability, durability and stuff: Perhaps you are under the impression that the Dodge automatic transmissions are substandard and are the weak link in an otherwise good drive line. How did this idea come to be?

First off, let's discuss the new 68RFE. It was introduced with the 6.7-liter engine in 2007.5. The initial power ratings for the engine was 350hp/650 torque. Not to be outdone by the competition, in February 2011 an engine rating of 350hp/800 torque was authorized for use with the 68RFE. (Notice, this rating was not released for manual transmissions—the clutch cannot take the torque.) Careful reading of the TDR magazine will reveal that the 68RFE is not being overpowered by the engine and the problems are few and far between.

I think the reason the 68RFE is doing well is two-fold: First, it is a good transmission. Second, owners of the 6.7 engine are not playing super hot rod/gonzo performance games with the engine and, therefore, not overpowering the torque converter lockup disc.

Now let's talk about the 48RE. This transmission has the same casting footprint as the previous 47RH/RE ('94-'03 vintage), the A618 ('89-'93 vintage) and the famous Chrysler 727 transmission that dates back to the 1960s. Matched to moderate horsepower and torque ratings, this transmission performed well, at least until 1994. Although engine ratings did not substantially increase in 1994, the factory used a plastic transmission line connector that, given time and heat cycles, was prone to leak fluid. If you ran the transmission low on fluid you would eventually overheat the transmission and end up with an expensive repair bill. Revised connectors were

implemented in or about 1997. However, a damaged reputation was already established.

Add to this damaged reputation story the fact that Turbo Diesel owners were discovering all kinds of horsepower adders for their 12-valve and 24-valve engines, and the transmission's reputation was further dinged. The extra horsepower/torque could, and did, overpower the 47RH/RE's torque converter lockup disc. Once the disc slips the transmission has to be rebuilt.

That's the transmission story, and the bad reputation kind of disappears with the Third Generation trucks and the 48RE and 68RFE. I fully understand the 68RFE story. I suspect the reason we don't hear complaints from the '03-'07 crowd with the 48RFE is that they know that their engine horsepower/torque modification has to be matched with a modified automatic transmission torque converter lockup. They listened and learned from the '94-'02 owners.

23 Body

In my review of the TSBs from '03-'09 (TDBG, pages 182-205) I did not see anything out of the ordinary in the body category. However, since your Third Generation truck is up to nine years old I am betting that the paint could use a bit of rejuvenation. TDR writer Doug Leno did an excellent article on truck detailing in Issue 68, pages 58-65. To rid your truck of those nasty swirl marks and etching from acid rain, this article is worth a reread.

24 Heating and A/C

Two words: blend door. Two more words: It happens. Reference material for the repair: Issue 66, pages 12-17.

25 Emission Control

Nothing to report.

26 Miscellaneous

Nothing to report.

Conclusion

It is difficult for me to put aside my bias for the Dodge/Cummins Turbo Diesel truck. However, the Third Generation vehicle is far better than the trucks from GM or Ford from the same vintage of years. The Ford owners had various engine problems to deal with in those years and the Duramax engine from GM was yet to be proven.

If you already own a Third Generation truck, I hope you agree with my assessment of your vehicle and that the article has provided a solid review for details that you had long since forgotten. For the prospective "Known That" owner my hope is that the data provided gives you the confidence to purchase the truck. The truck is not without its faults, but we TDR members are here to provide you with an information resource that is unmatched anywhere else.

Robert Patton  
TDR Staff

# Brakes

ISSUES 40-45, 50

As a subscriber to a number of publications, your editor happened upon an article on braking systems in [Grassroots Motorsports](#). As I searched for an answer to better brake performance, I realized that I was concentrating my efforts (read: money) somewhat in the wrong direction. After reading author James Walker's article, I knew that I had to get this information to the TDR audience. I made some phone calls to inquire, and now I am pleased to present James' article complete with some custom tweaks for us, the Turbo Diesel audience.

## BRAKING SYSTEMS IN PLAIN ENGLISH

By James Walker, Jr. of SCR Motorsports

Readers of this publication often see advertisements describing brake upgrades available to diesel enthusiasts. However, before any of us go running off to the aftermarket for our own NASCAR six-piston calipers, F1 carbon-fiber rotors, and 50 feet of stainless steel braided brake lines, it would be wise to take a deeper look into braking systems. You just might find that once you gain a fundamental understanding of what each of these components **really** does (and more importantly, what each does **not** do), you will be better prepared to make the right decisions when modifying (or choosing not to modify) your own rides.

## WHAT DO BRAKING SYSTEMS REALLY DO?

So, here comes the first surprise. Your brakes do not stop your truck. The traction available between the road and the tire's four contact patches—where the rubber meets the road, so to speak—is the limiting factor when everything comes to a halt. For all intent and purposes, this could complete our article, but because a two paragraph story doesn't read too well, I suppose we should continue to discuss the actual purpose of the braking system.

Of course, the next question is: "What do the brakes do?" In plain English, your brakes convert the energy of motion into heat. An engineer would say the brakes are responsible for turning the kinetic energy of your speeding truck into thermal energy. The engineer would also be able to tell us (kind of funny, but I am an engineer myself) that for every percent increase in vehicle weight, there is an equal percent increase in the amount of energy, and consequently, heat generated. For example, load up your 5000 pound truck to 8000 pounds (an increase of 60%) and your brakes will run 60% hotter, everything else being equal.

Even more interesting is the relationship between speed and heat. Unlike the one-to-one relationship with vehicle weight, the heat goes up with the increase in speed squared. In other words, if you make a stop in your truck from 45mph and another from 65mph (an increase of 44%), the amount of heat would increase by 209%! Little changes in speed make a big difference in heat, and as we will find out later, heat is usually the enemy.

Now let's look at each of the pieces of the braking system puzzle to understand just exactly how they convert the energy of motion into heat, and how this process results in tire traction stopping the truck.

Author's disclaimer: while the concepts, analysis, and functional descriptions of the brake system components described herein are 100% applicable to the TDR reader, the actual sizes and physical relationships used in this example are not from an actual Dodge product. Many of the values are from my race car, but the rest were chosen to make the math easy.

## THE MIGHTY BRAKE PEDAL

I'm hoping that you are all familiar with the brake pedal. But, while most of us probably think of the brake pedal only as the flat part that makes contact with the foot, remember that an equally important part of the brake pedal assembly, the output rod, continues out of sight. Together, these parts constitute the brake pedal assembly.

The sole function of the brake pedal assembly is to harness and multiply the force exerted by the driver's foot. It does this thanks to a concept known as leverage. We all learned the concept of leverage on a teeter-totter—the farther you sit from the middle (the pivot), the more weight you can lift on the other end. In the case of the brake pedal assembly, the pivot is at the top of the brake pedal arm, the pad (where we step) is on the opposite end, and the output rod is somewhere in between. In the example illustration (Figure 1), a driver input force of 90 pounds is multiplied by the 4:1 ratio into 360 pounds {90 lb. x 4} of output force.

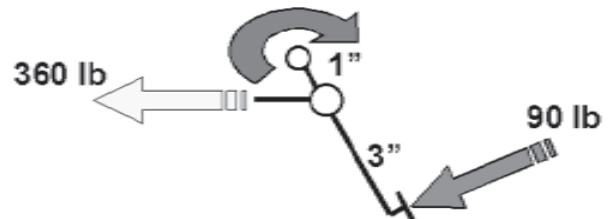


Figure 1 – The brake pedal as a simple lever

Does the output rod directly stop the truck? No. So would you want to make any changes to the brake pedal, and if you did, how would this impact the brake system performance? There are several answers, each with their own set of pros and cons:

- Increasing the ratio (8:1, for example) would further amplify driver input force, but would make the pedal travel through a longer distance to achieve the same output. In the given example, the 90 pound input would generate 720 pounds output, but with twice the pedal travel.
- Decreasing the ratio (3:1, for example) would reduce the overall size and weight of the brake pedal assembly, but would decrease the amount of amplification—the 360 pounds in the example would fall to just 270 pounds. To generate the same 360 pound output, the driver would need to press the pedal with 120 pounds of effort!

So, will changing the brake pedal make the truck stop any faster? Not by itself. But while one can tune the pedal output force and pedal travel characteristics by making changes to the pedal ratio, these parts (because of their complexity) are rarely found in the aftermarket.

### THE MASTER CYLINDER

The next step in the brake system is to convert the amplified force from the brake pedal into hydraulic fluid pressure. The master cylinder, consisting of a piston in a sealed bore with the brake pedal output rod on the one side and brake fluid on the other, performs this task. In addition, on most diesel-powered vehicles there is an auxiliary power supply unit commonly known as HydroBoost lumped into the assembly.

HydroBoost uses power steering fluid under pressure to increase the force coming from the brake pedal output rod before it pushes against the master cylinder piston. As the pedal assembly output rod pushes on the piston, the piston moves within the cylinder and pushes against the fluid, creating hydraulic pressure. It's really that simple; however, in order to determine how much pressure is generated at the master cylinder, we will need to dig into a few fluid calculations. Don't flip to the classified ads just yet!

The pressure generated at the master cylinder is equal to the amount of force from the brake pedal output rod (plus the HydroBoost contribution, say, an additional 325 pounds, for a total of 685 pounds) divided by the area of the master cylinder piston. If we assume a master cylinder diameter of 1.25 inches (with a resulting area of about 1.23 square inches), the calculated pressure will be 558 pounds per square inch (PSI) from the 685 lbs. of output force from above ( $685 \text{ lb.} \div 1.23 \text{ in}^2$ ).

Whew—no more math for a minute, just stare at Figure 2 for a while.

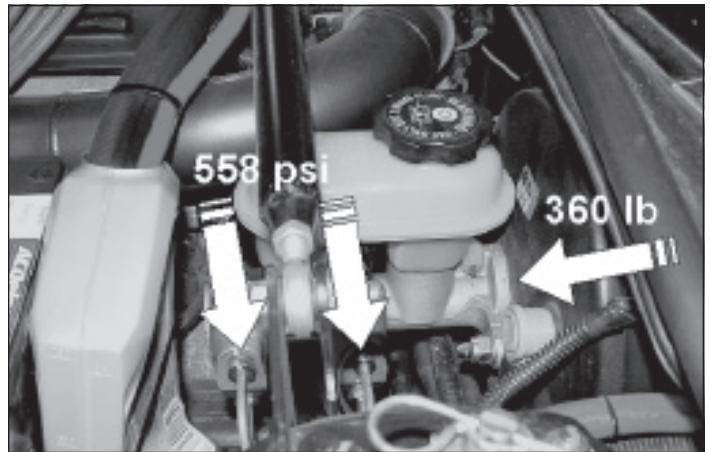


Figure 2 – The master cylinder generating pressure

So, does this pressurized hydraulic fluid stop the truck? Again, the answer is no, but like the brake pedal making changes to the master cylinder can impact other characteristics of the brake system:

- Increasing the master cylinder piston diameter will decrease the amount of pressure generated in the fluid for a given input force. Seems backwards, but that's the way it works out. In the example above, if a 1.375" master cylinder were to be substituted, the output pressure would fall to approximately 460 PSI—a pressure reduction of nearly 20% for a +0.125" change in diameter. Small changes here make a big difference.
- Decreasing the master cylinder piston diameter works the same principle in reverse. Swapping in a 1.125" master cylinder will increase pressure to just about 700 PSI—this time a 25% increase for a -0.125" change in diameter.

Given the relationship between master cylinder piston diameter and hydraulic force, it may seem desirable to use the smallest master cylinder possible. However, the braking system has to have enough additional hydraulic fluid on hand to fill all the extra volume caused by the flexing of components during the compliance phase (this is one reason that the brake fluid reservoir is so large as well). Unfortunately, this is accomplished by increasing the diameter of the master cylinder, which, we just learned, reduces the pressure generated! Therefore, one has to make sure that the master cylinder has a large enough diameter to meet the fluid volume requirements of the system, but small enough to generate the pressure required. (There's never an easy answer, is there?)

### THE BRAKE TUBES AND HOSES

On the surface, the brake tubes and hoses have one of the easiest jobs in the braking system—transporting the pressurized brake fluid away from the master cylinder to the four corners of the car. It would be ideal to use the most rigid material possible to minimize the compliance in the system. However, since the braking components at the wheels (calipers, pads, and rotors) are usually free to move around with the wheels and tires, a flexible portion is required—and flex equals compliance.

Traditionally, auto manufacturers have used rigid steel tubing and a short length of rubber coated nylon tubing to make the connection to the moving stuff, but even this short section of flexible tubing can significantly affect compliance. For this reason, it is sometimes preferred to replace the rubber hose with a nylon tube covered by stainless steel braiding (see Figure 3). Most people notice the reduction in brake pedal travel due to the reduced compliance immediately, but it usually depends on how old and flexible the old rubber coated hoses were at the time of replacement.

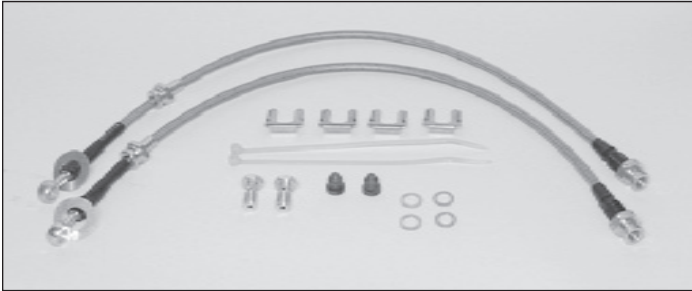


Figure 3 – Stainless steel brake hoses

Although those cool-looking stainless steel brake lines will not make your truck stop any faster on their own, the decrease in compliance and improvement in pedal feel can make a driver much more confident. They will probably provide some increased level of resistance to damage from flying debris as well. Did I mention they look cool?

### THE CALIPER

The caliper is one of the most familiar components, yet sometimes the most misunderstood. Like the master cylinder, the caliper is just a piston within a bore with pressurized fluid on one side. While the master cylinder used mechanical force on the input side to create hydraulic force on the output side, the caliper does the opposite by using hydraulic force on the input side to create mechanical force on the output side. The top view shown in Figure 4 illustrates how the pressurized brake fluid working against the back side of the piston is converted into a squeezing or clamping force.

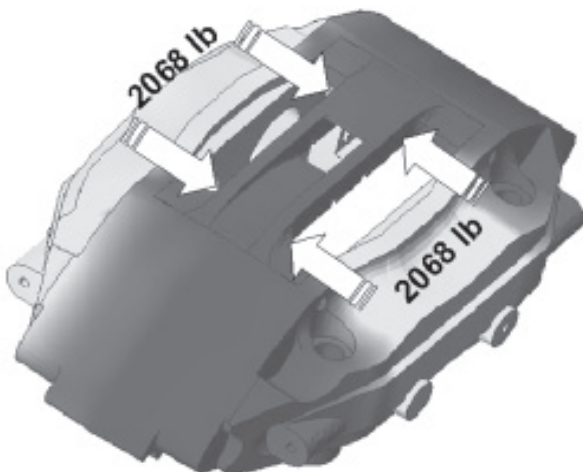


Figure 4 – Caliper clamping force

In order to calculate the amount of clamping force generated in the caliper, the incoming pressure is multiplied by the area of the caliper piston. In our example, the 558 PSI that had been generated at the master cylinder has traveled through the brake lines and hoses and is pushing against two 1.5" pistons per caliper. Therefore, the effective area of the caliper will be equal to two times the area of a single 1.5" piston. Working the numbers reveals that 558 PSI will generate 2,068 pounds of clamp load  $\{558 \text{ PSI} \times 1.84 \text{ in}^2 \times 2\}$ .

As you have probably already guessed, increasing the caliper piston diameter increases the clamp load for a given input pressure—but again, this does not stop the truck. Putting on bigger calipers might seem like a good idea at first, but the tradeoffs might make you think twice:

- Increasing the piston diameter will increase the compliance in the system (bad news for pedal feel!)
- Increasing the piston diameter will increase the size and weight of the caliper (bad news for unsprung weight!)
- Increasing the piston diameter will increase the fluid volume requirement of the system (bad news for master cylinder sizing!)

So, when thinking about that big-piston caliper conversion, keep in mind that the size and number of caliper pistons on your truck were originally matched to the brake pedal and master cylinder to generate an appropriate clamp load for a given brake pedal input force. Changing any one of the components will shift the balance one way (increased pressure required) or the other (higher pedal forces required) to generate the same clamp load. Remember, bigger calipers don't create any more stopping power and they do not decrease stopping distance; they just generate higher clamp loads for a given pressure input.

One final caliper note of interest: you may have heard the terms "fixed caliper" (indicating that the caliper body is bolted directly to the suspension upright) and "floating caliper" (indicating that the caliper body is free to float on sliding guide pins). Although there are pros and cons associated with each type, there is not enough room in this article to dig into the details of their design differences. For now, let it suffice to say that the above math works out the same for either design.

So, in our example the brake pedal, master cylinder, and caliper have amplified the original 90 pounds of driver input to over 2,000 pounds—an increase of more than 22 times—but we still haven't stopped the truck (keep thinking traction, traction, traction).

### THE BRAKE PADS

This part might surprise some and offend others, but there is a big misconception that changing brake pad material will magically decrease your stopping distances. In fact, you may have even seen published data which attempts to correlate stopping distance to friction coefficient. Although it may appear that there is a relationship between the two, there really isn't. Here's why.

The brake pads have the responsibility of squeezing on the rotor (a big steel disc which is mechanically attached to the road wheel) with the clamping force generated by the caliper. There is a lot of

black magic surrounding the material composition and formulation of the friction puck, but what really matters is the effective coefficient of friction between the brake pad and the rotor face.

By knowing the clamp load generated by the caliper and the coefficient of friction between the pad and rotor, one can calculate the force acting upon the rotor. In this particular example, let's assume the brake pads have a coefficient of friction of 0.45 when pressed against the rotor face. The rotor output force is equal to the clamp force multiplied by the coefficient of friction (which is then doubled because of the floating design of the caliper)—or in this case  $\{2,068 \text{ pounds} \times 0.45 \times 2\} = 1,861 \text{ pounds}$  (see Figure 5). Nothing magical about it.

By increasing the coefficient of friction of the brake pads, the results are the same as increasing the caliper piston diameter—higher forces will be generated for the same input. But as before, this force alone is not what stops the truck (remember: traction, traction, traction). So why change brake pad materials in the first place? Because increasing the coefficient of friction can allow for the use of smaller/fewer caliper pistons and/or will reduce the amount of pedal force that the driver needs to apply in order to generate a given rotor output force.

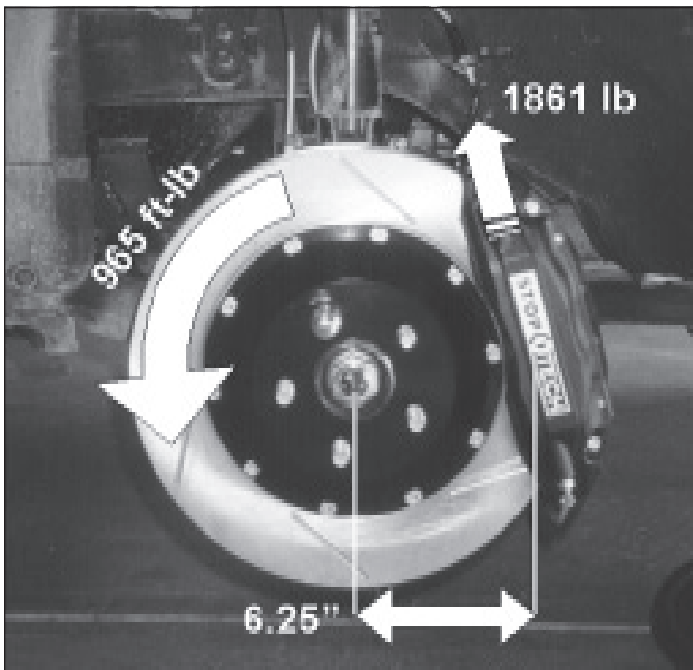


Figure 5 – The brake corner in action

That's about it from a design standpoint; however, there is a final point to consider—heat! In the example above, the rotor output force was calculated assuming that the coefficient of friction between the brake pad and the rotor was constant, but in the real world this is not the case. As the temperature of the components change, the physical properties of those components change, and in the case of the brake pads, the coefficient of friction can change dramatically! While pads might have a coefficient of 0.45 around town, after a few trips down the mountain and fully loaded, the coefficient can drop to below 0.10, a condition commonly known as brake fade. (Note: this should not be confused with brake fluid fade which results from water in the brake fluid turning to vapor at high temperatures.) If

you have ever experienced brake fade firsthand, you know this can be kind of, well, unsettling to say the least.

So, back to the black art of friction materials. While a coefficient of friction number is a nice data point to consider when modifying a braking system, what is even more important is the ability of the material to maintain that coefficient under a variety of temperatures brought on by driving and towing conditions. Brake pads with radical changes in coefficient over their operating range are not your best friend. Be sure to select one that remains relatively stable under the operating conditions you are expecting, but don't expect any shorter stopping distances, because, the brake pads don't stop the truck!

## THE ROTOR

The rotor actually stops the truck—just kidding! Like the other parts of the system mentioned so far, the rotor does not stop the truck; however, unlike the other braking system components, the rotor serves two purposes. In order of appearance, they are:

- 1) The rotor acts as the frictional interface for the brake pads. But because it is a spinning object, it reacts to the output force by absorbing the torque created. Any time a force is applied to a spinning object a torque is generated. In this case, if we assume the force to act at a point midway across the rotor face (6.2" from the center of rotation in our example) then the torque is equal to about 964 ft-lb.  $\{1,861 \text{ pounds} \times 6.2" \div 12 \text{ inches per foot}\}$ . Take a second look back at Figure 5 to follow along.
- 2) The rotor must also absorb the heat generated by the rubbing of the brake pads against the rotor face.

In the case of item (2) above, the rotor dissipates the heat generated by warming the air surrounding the rotor (this is why brake cooling ducts are so useful), but where does the torque go? The calculated 964 ft-lb. sure is a lot of torque (most diesel owners would appreciate those kinds of torque numbers), and it has to go somewhere. . .

## THE WHEELS AND TIRES

Time to get down to business—and time to stop the truck. Because the wheel and tire are mechanically bolted to the rotor, the torque is transferred through the whole assembly—rotor to hub, hub to wheel, and wheel to tire. And now, the moment we have all been waiting for...

It is the traction between the tire and the road that reacts to this torque, generating a force between the tire and the road that will oppose the motion of the truck. The math looks just like the equation to calculate the torque in the rotor, but in reverse. Crunching the numbers based on a 275/35R17 race tire with a rolling radius of 12.2 inches (there go those race car numbers sneaking back into a TDR article again) shows that a force of 942 pounds is generated between the tire and road, opposing the motion of the vehicle. Ladies and gentlemen, this is what stops the truck—**not** the brake pads, **not** the rotors, **not** the cool stainless steel brake lines—it's road reacting against the tire!

Now, in order to finish the article, all that is necessary is to add up all the forces (remember, there is a force acting on every tire with a brake) and run through a little more math. In case you haven't noticed, we engineers just love this math stuff!

### ADDING THE FORCES

As that famous guy Newton said,  $\text{force} = \text{mass} \times \text{acceleration}$   $\{F=MA\}$ . Or stated another way, the acceleration (or deceleration as the case may be) of an object will be equal to the sum of all of the forces acting on the object divided by the weight of the object.

Before we can sum up all the forces, there is one last little important fact to consider—the tire forces are not the same for the four corners of the truck. Due to the static weight distribution of the truck, the location of the center of gravity of the truck, and the effects of dynamic weight transfer under braking (just to name a few), the rear brakes are designed to generate much smaller forces than the forces generated by the front brakes. For the sake of argument, and for this exercise, we'll say the split is 80% front and 20% rear, but the actual distribution is dependent on the specific vehicle configuration.

So, if each front tire generates 942 pounds of force, then we can calculate that each rear tire generates 20% of that, or 188 pounds. Adding up the four corners now gives us a total of 2260 pounds of force acting on the vehicle between the four tires and the road.

Rearranging Newton's homerun mentioned above,  $\{\text{decel} = \text{force} \div \text{weight}\}$ , we can calculate that the total deceleration of the vehicle is about 0.85g's, or  $\{2260 \text{ pounds force} \div 2640 \text{ pounds weight}\}$ . Easy, right? Figure 6 wraps it all up for us.

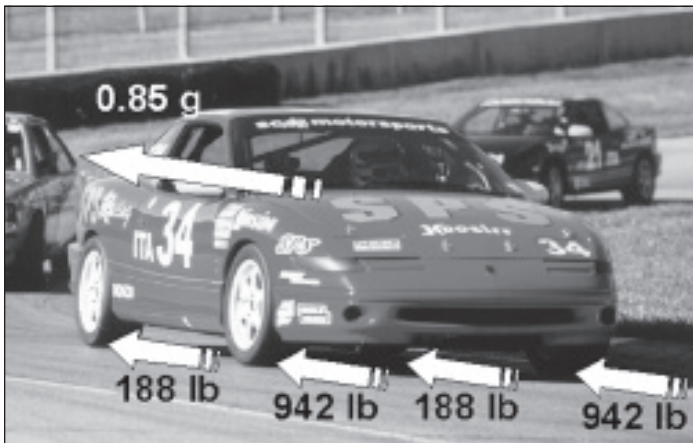


Figure 6 – Look! A real race car!

Doing a little backwards math here that TDR readers will appreciate, we can calculate that if our vehicle is generating 2260 pounds of force through tires that are 24.2 inches tall, our braking system has created 2223 foot-pounds of torque. Can that possibly be right?

While this may sound like an unreasonable number, these torque levels are commonplace in braking system design and analysis. It takes torque to accelerate, but it also takes torque to decelerate. Consider that a typical unloaded truck can easily stop from 60mph in well under four seconds on dry pavement (assuming adequate

traction). In contrast, just imagine how much engine torque it would take to accelerate your truck from rest to 60mph in that same sub-four second window. Yes, there is a transmission and final drive reduction in the acceleration equation, but in nearly every case factory braking systems are designed to generate more torque than the factory powertrain is capable of producing.

Brake guys chuckle to themselves when engine guys brag about their torque output.

### CALCULATING THE DISTANCE

Okay, last equation of the day. Given a vehicle speed of, say, 100 miles per hour, and the deceleration level from above, we can now calculate the distance required to bring the truck to a stop. But, in order to make sure the answer comes out in feet we first need to juggle the numbers around a little bit:

100 miles per hour = 147 feet per second  
0.85g's = 27.0 feet per second per second

Apply the equation for stopping distance  $\{\text{distance} = (\text{initial speed})^2 \div (\text{deceleration} \times 2)\}$  and lo and behold, exactly 400 feet are required to bring this truck down to a stop from 100 miles per hour (given our original pedal input force of 90 pounds). Tah dah! The truck is now stopped.

### LIMITING FACTORS

From this example, it would appear that we might be able to make the truck stop in a shorter distance. Let's investigate these two options further:

- Change the brake system to increase the force between the tire and the road for a given pedal input force
- Press on the brake pedal harder

These two changes will shorten the truck stopping distances for sure, but only up to a point. Anyone who has ever driven on an icy road will get this right away. As the brake pedal force is gradually increased, the deceleration rate will also increase **until the point at which the tires run out of traction and lock up**. Beyond this point, additional force applied to the brake pedal does nothing more than make the driver's leg sore. The vehicle will continue to decelerate at the rate governed by the traction between the tires and the road. As you know, the traction of a given tire on ice is much lower than the traction of that same tire on dry pavement. This is exactly why stopping distances are longer on slippery surfaces.

You can take this one to the bank. Regardless of your huge rotor diameter, brake pedal ratio, magic brake pad material, or number of pistons in the calipers, your maximum deceleration is limited **every time** by the tire-to-road interface. That is the point of this whole article. Your brakes do not stop your truck. Your tires stop the truck. So while changes to different parts of the brake system may affect certain characteristics or traits of the system behavior, using better tires is ultimately the only sure-fire method of decreasing stopping distances.

## SO WHY WOULD ANYONE WANT TO MODIFY THEIR BRAKES?

So, if changing braking system components does not provide shorter stopping distances, why even consider changes in the first place? Why not just leave the brakes alone and buy new tires? Well, as we have implied earlier in this article, making changes to your braking system can have a very real, very significant impact on four other areas of brake system performance (other than stopping distance).

- **Driver tuning.** Modifying your brake system component sizing (brake pedal ratio, master cylinder piston diameter, caliper piston diameter, rotor diameter) can be performed to adjust the feel of the truck to suit the driver's tastes. Some drivers prefer a high, hard pedal while others prefer a longer stroke. In this regard, tuning your brakes is a lot like tuning your shocks—every driver likes something different, and there is no right answer within certain functional limits. These components can be adjusted in small steps to achieve a feel that the driver prefers.
- **Thermal control.** Modifying your brake system mass (rotor weight) can be utilized if there is a thermal concern in the braking system. If your brakes work consistently under your driving conditions, then adding size to the braking system will accomplish nothing more than increasing the weight of your vehicle. But if high temperatures are having an adverse effect on braking system performance, or other components in general (wheel bearings for example), then you should consider “super-sizing”. Naturally, other constraints (wheel diameter, for example) may make super-sizing impossible, but adding rotor weight is the best way known to reduce brake temperatures. Figure 7 shows just how far one car go!
- **Temperature sensitivity.** Modifying your brakes to address the presence of high temperatures (brake pad material and brake fluid composition) should be considered if your thermal concerns cannot be resolved by super-sizing. This is really just a Band-Aid for undersized systems. One might argue that it is more cost-effective to install better brake pads and brake fluid than it would be to upsize the rotors, but all that heat still needs to go somewhere—and more often than not it will find the next weak link in the system.
- **Compliance.** Any changes that you can make to your braking system to reduce compliance will increase the overall efficiency of the system—improving pedal feel, wear, and stop-to-stop consistency. Think of it as balancing and blueprinting your braking system.



Figure 7 – Filling the wheel with brake hardware

In summary, brake system modifications have their place to help make your ride more consistent, predictable, and user-friendly; however, if your ultimate goal is to decrease your stopping distance, look no further than the four, palm-sized patches of rubber connecting your ride to the ground.

**James Walker**  
TDR Writer

### ABOUT THE AUTHOR

James Walker, Jr. of scR motorsports races a 1992 Saturn SC in the SCCA's ITA class. With a degree in vehicle dynamics, his brake systems background has included tours of duty with Delphi, TRW, GM, Bosch, and the Ford Motor Company. And, when spare time allows, he serves as a consultant to STOPTECH, an industry leader in high-performance braking systems. To find out more about James and his team, visit their website at [www.teamscR.com](http://www.teamscR.com).

## BRAKE PAD SELECTION

by James Walker

*In Issue 40 we asked engineer-writer James Walker to adapt his article on brake systems for the TOR audience. I had found James' original in Grassroots Motorsports and was impressed by his common-sense writing style. As an introduction to this issue's "Brake Pad Selection" I'll pull a quote from his Issue 40 article, "modifying our brakes to address the presence of high temperatures (brake pad material and brake fluid composition) should be considered if your thermal concerns cannot be addressed by super-sizing." Super-sizing sounds expensive, so let's hear what James has to say about brake pad selection.*

In Issue 40 we learned that as brake pedal force (how hard the driver is pushing the pedal) is increased, the truck's deceleration rate will also increase (the truck will slow down more) until the point at which the tires run out of traction and lock up (or go into ABS if so equipped). Beyond this point, additional force applied to the brake pedal does nothing more than make the driver's leg sore. Tire-to-road traction was discovered to be the limiting factor for stopping distance, and here in Issue 41 we are back to tell you that fact hasn't changed.

At the same time, we also learned that there were several other benefits to changing brake system characteristics which could benefit the typical TDR reader. Even though race-bred big brake kits are probably beyond the scope of most of the audience, tangible improvements can still be had in the areas of driver tuning, temperature sensitivity, and compliance. Because we don't want this magazine to turn into a 200-page essay on brake system design, for now let's just look at the most common upgrade of all: the brake pads.

## BRAKE PADS 101

One of the single most common brake upgrades is the replacement of factory pads with premium, high-performance, or heavy-duty brake pads. However, because there are no industry standards for what constitutes a "premium," "high-performance," or "heavy-duty" brake pad, the consumer is best advised to do a bit of research beforehand to determine if the four pieces of friction material in the cardboard box (Figure 1) are suitable for their purpose.



Figure 1 - Typical Brake Pads

### Driver Tuning

One of the brake pad's most significant characteristics is its effective coefficient of friction. In general, brake pads from the factory are sold with a relatively low coefficient of friction (typically in the 0.30 to 0.35 range) in order to make the brakes as noise-free as possible. While there are about a bazillion other reasons why this range is so common, let's suffice it to say that in the aftermarket there are not as many restrictions or constraints placed on the friction material performance. It's basically a case of anything goes, and as a result you can buy pads with just about any friction level you desire.

Increasing the coefficient of friction just a small amount can cause the brake system feel to change dramatically. For example, if a factory brake pad with a coefficient of 0.30 was replaced with an aftermarket brake pad with a coefficient of OAO, the result would be the same as if the driver pressed on the brake pedal 33% harder! Because the relationship of driver force-to-deceleration is generally linear, any change in friction level (on a percentage basis) will directly result in an equal level of increased deceleration. In other words, the driver now has to hit the pedal with less force to achieve the same level of deceleration so the truck feels like it is stopping faster. This is typically regarded as a good thing.

Unfortunately, like most things in life nothing is free. Even though this sounds like a good deal, as soon as the friction level is changed other brake system characteristics can be impacted inadvertently. ABS calibrations, brake balance, noise, wear, dust, and roughness are just some of the possible areas of concern. Buyer beware, the only brake pad which has been certified to work in harmony with your truck is the pad that came from the factory! Increased friction may be on your wish list, but be ready to deal with these side effects should they arise.

## Temperature Sensitivity

For those owners who do a significant amount of towing or heavy hauling, temperature sensitivity might be the number-one priority. Increased friction levels are great, but if the pad rapidly loses friction as the temperatures go up (a phenomenon known as brake fade), then all of a sudden the truck doesn't want to stop. This is typically regarded as a bad thing. What makes the issue even more complicated is that two brake pads with identical advertised friction levels may have completely different temperature sensitivity profiles (see Figure 2).

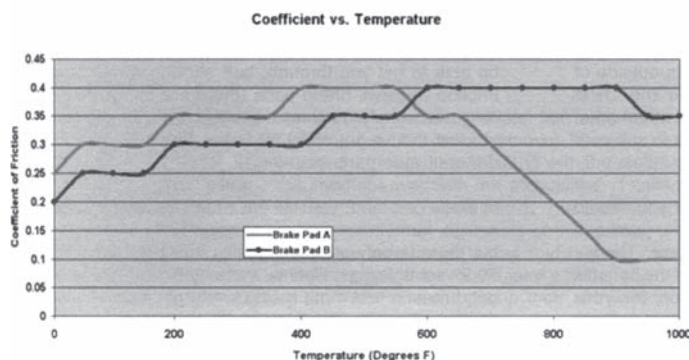


Figure 2 - Coefficient vs. Temperature

While the pads from the factory were chosen by the manufacturer to provide a certain amount of resistance to brake pad fade, there are many choices in the aftermarket which can tolerate even higher temperatures before the inevitable drop-off occurs. Keep in mind that like increasing the coefficient of friction, changing brake pad formulation to resist these higher temperatures will come with a penalty in some other area of performance. Compromise is the rule, and typically those pads with higher temperature thresholds will give up noise isolation, pad life, or cold temperature performance as a result. Note that not every high-temperature pad will degrade performance in all of these areas, but be prepared!

## Compliance

Believe it or not, brake pads are pretty soft and spongy objects. As a result, every time you step on the brake pedal, part of your leg effort is being used to squish the molecules of the brake pad material closer together instead of generating brake torque. While this is certainly not the most efficient of situations, it simply cannot be avoided.

That said, changing from brake pad A to brake pad B for driver tuning (friction level) or temperature sensitivity (fade resistance) can bring with it a change in the lining compressibility, which in turn can change the brake pedal feel. Those brake pads with more compressibility will generally exhibit a softer, spongier pedal while those with low compressibility will typically provide the driver with a more firm brake pedal.

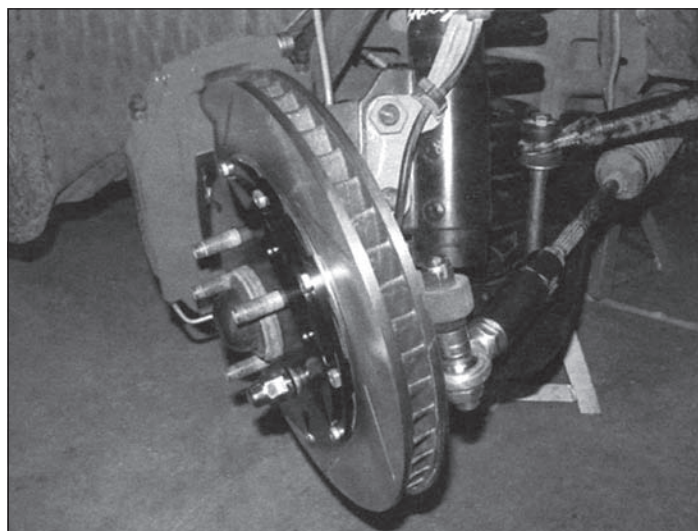
Unfortunately, brake pads with the highest friction levels usually have the highest compressibility, so the pedal feel benefits of the higher friction levels can be masked by the compliance loss of the pad itself. Just the opposite can be true as well, so those brake pads with the lowest friction levels can provide the most firm pedals. Ironical, but that's the harsh reality of the situation.

## All of Those Other Things

Naturally, in addition to stopping the vehicle, everyone wants a brake pad that doesn't squeal, doesn't create piles of brake dust, doesn't pulsate, and lasts for 100,000 miles. Rest assured that if this miracle brake pad configuration was discovered today, every other brake pad manufacturer would be out of business tomorrow. Sadly this perfect brake pad does not exist, so we are forced to make educated decisions regarding our needs and trade-offs.

What it comes down to is this: your truck came from the factory with a brake pad designed and developed specifically for a certain set of operating conditions. If your vehicle usage is outside of that window, or if you simply want to enhance the OEM performance in some specific way, there are several aftermarket brake pad manufacturers ready to sell you a product to suit your needs.

However, before you spend your hard-earned dollar you should clearly define exactly what you are expecting from your purchase and what negative side effects you are willing to accept. There's no free lunch in brake pad land; but if you are aware of the benefits and trade-offs, you can make the best decision for your application. Make every attempt to find a vendor or manufacturer that can walk you through these decision-making steps, as they will know their product's strengths and weaknesses better than anybody.



How about super-sizing?  
Check out these StopTech racing brakes.

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## Making the Best Decision

Unlike tire UTQG codes which make an attempt to characterize a tire's performance in several different areas (wet traction, temperature sensitivity, wear rate, and so on), no such information exists from the brake pad manufacturers. Short of a cryptic "edge code" which may or may not be available (and is, frankly, meaningless to the consumer), it's a classic case of buyer beware.

However, there are a few helpful hints and rules of thumb that can go a long way toward helping you make the best choice for your particular application. Note that this list is far from all-encompassing, but should get you well on your way toward making an informed purchase when your truck begins to squeal, shake, and s-s-h-h-u-u-d-d-d-e-e-r-r.

Stick with a name brand brake pad. While this may sound obvious, there are countless no-name products on the market that could compromise your brake system performance. Nobody can tell how well a brake pad will perform by looking in the box, so rely on the company whose name is printed on the side. In a pinch anything that fits may be able to get you through, but sticking with Performance Friction or Hawk brand pads (there are many more-these are just examples) will most likely result in a more consistent product than a set of \$9.99 Super Stoppers from the local discount auto parts counter.

In brake pad land, you still get what you pay for. Brake pad design, formulation, and manufacturing is not rocket science, but there is only so much quality that can be baked into a \$9.99 set of linings, lifetime warranty or not. There is a very good reason that most racing brake pads cost hundreds of dollars-the materials that provide consistent friction at high temperatures cost more than those that fall apart on lap three. These same materials are required in severe use towing and hauling applications, so don't expect to pay any less!

Listen to recommendations from people using their trucks the same way you do. Word-of-mouth advertising is still one of the best ways to publicize a product known, and those brake pads with extreme performance, either good or bad, are certainly going to get noticed. Just because everyone is using a set of particular pads doesn't mean it's the best choice for you, but it sure can be a great place to start.

Don't be afraid to call the brake pad manufacturer, dealer, or distributor directly to get a pad recommendation. Typically a manufacturer will have several pad compounds to choose from, and the best fit to your application may not be obvious. Share all of your expectations and requirements and see what they have to offer. Naturally you will have to temper their recommendation with the knowledge that they are also trying to sell you their product, but it never hurts to ask.

In closing, beware of the brake pad that claims to do everything well. More often than not, these brake pads are made of snake oil.

Happy stopping!

**James Walker**  
TDR Writer

## TWENTY-ONE BRAKE QUESTIONS

by James Walker

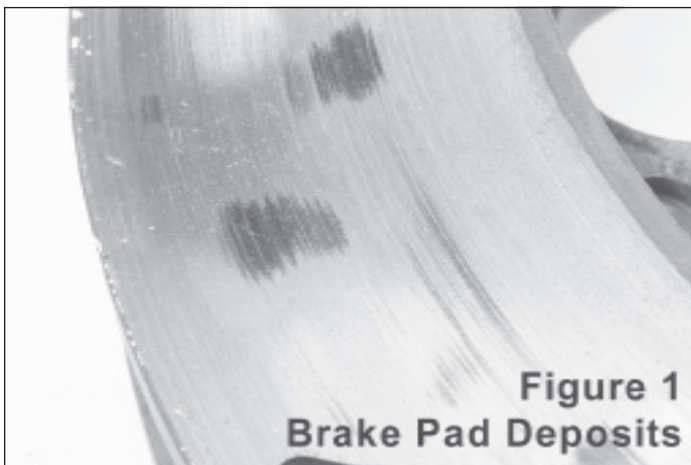
Our two-part series in Issues 39 and 40 on brake systems and brake pads has generated many inquiries. I took time to consolidate the questions and then sent them to our resident brake guru, James Walker, Jr., for his response.

With issues 40 and 41 in your library and the following "Twenty-one Brake Questions" article in hand, I am hopeful that we have given the brake topic sufficient coverage. Read on and I think you will agree!

### 1. What causes my rotors to warp? Is it because I am driving my truck too hard?

In 99% of all cases (not a scientific number, but close enough), warped rotors are not physically warped at all. The vibration and pulsation that is felt in the steering wheel, brake pedal, and floorboard is almost always caused by rotor disc thickness variation, or TV.

TV is generally created in one of two ways. Most commonly, when the truck is parked for extended periods of time, a layer of corrosion (rust) can form between the brake pad face and the rotor. When the truck is then moved, there is a slight high spot on the rotor face which will then wear at a different rate than the surrounding material (see Figure 1). Over time, this condition will only get worse until you feel it in your foot.



TV can also be generated through overheating of the rotor. When the rotor gets really, really warm, it will actually develop isolated spots which are hotter than the surrounding material. These hot spots will also accelerate wear locally, creating a thick and thin pattern on the rotor face. Again, this will only get worse with time until the TV is felt by the driver and his (or her, as the case may be) passengers.

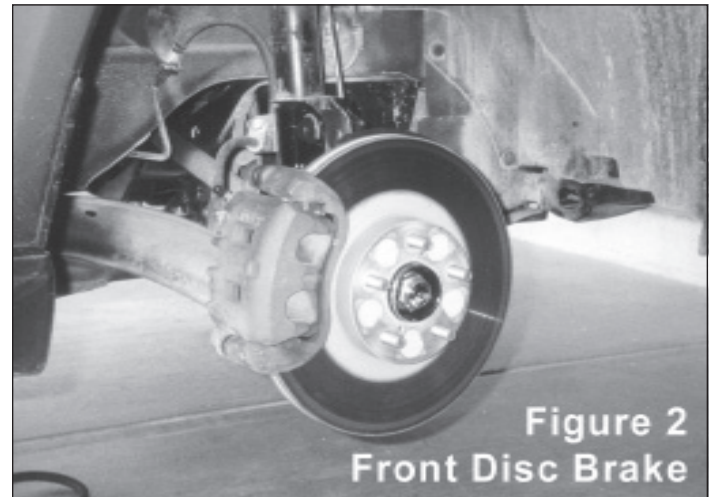
### 2. Will changing my brake pads reduce the tendency to generate rotor TV?

Actually, yes. If your truck is typically left outside in the weather for extended periods of time, it might be best to select a non-metallic brake pad. These brake pads reduce the tendency to generate corrosion between the pad and the rotor. Over time, this may reduce the generation of TV.

However, it's not a free lunch. Non-metallic pads also have the tendency to be less-suited for towing or severe duty applications. So it's a trade-off.

### 3. When I have my front end off the ground and spin the tires I feel the brakes dragging more than I expect. When I lift the rear end off the ground and do the same thing, I do not feel nearly as much drag. Is this normal?

Rest assured, this is completely normal. By design, disc brakes (see Figure 2) will always have a slight amount of drag.



Disc brake calipers employ a square sectioned piston seal to pull the caliper piston back into its bore when the brake pedal is released. However, the seals are designed so that they don't pull the pistons back quite so far that the brake pedal feels mushy when you need it the next time. This compromise in design leads to brakes that do exhibit a small amount of drag when released, but minimal pedal dead travel when applied.

Drum brakes (as found on the rear of your Ram), on the other hand, use real-live retraction springs to pull the brake shoes completely off the drums when released. This leads to much less running drag, and because the rear hydraulic system is smaller than the front, the trade-off in pedal dead travel is acceptable.

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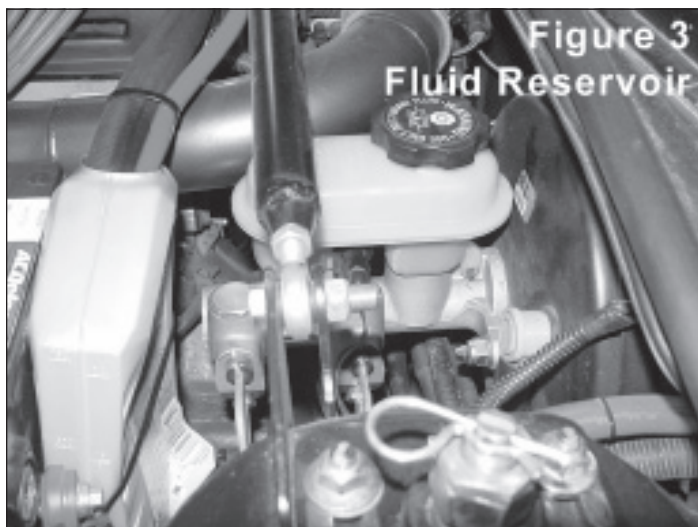
**4. I'm putting new brake pads on my truck and would like to know how they should be "broken-in." Is there a defined procedure I should be following?**

On street-driven vehicles (as opposed to race cars), a "burnish" procedure will go a long way toward ensuring good system performance. In short, running through a series of medium deceleration stops from approximately 60mph to 10mph (allowing time for the parts to cool inbetween to avoid pad fade) should do the trick. This procedure basically allows the brake pad and rotor wear surfaces to get to know each other so that maximum contact is made between the two.

Certain race car-type brake pads require a procedure known as "bedding-in," in which the pads are allowed to get hot enough during the break-in procedure to leave a uniform deposit layer on the rotor face. However, for street-driven vehicles this is not usually necessary or recommended.

**5. How do I know when to change the brake fluid in my truck? It looks kind of brown and murky through the reservoir bottle.**

This is a tough one to answer. Here in the US, most auto manufacturers do not specify a replacement interval for brake fluid (see Figure 3), so consumers are left to their own devices. Not surprisingly, the default action has become to never touch the stuff even though regular replacement has real benefits!



As brake fluid ages it absorbs water. Unfortunately, when the water gets sucked up, it lowers the boiling point of the fluid, and it doesn't take too long until the resulting mixture has a boiling point much lower than when it was new.

So why is this important? During severe towing or hauling (or even high-speed driving) the brake fluid can see temperatures of 300°F or even more! When you consider that the government requirement for new DOT 3 fluid is only about 400°F, it doesn't take much time until the fluid degrades to the point where it can be subject to boiling in the line!

As boiling brake fluid doesn't do much to help slow your truck, your best defense is to change your brake fluid on a yearly basis if you consistently get the brakes toasty warm. If low-speed around town driving is more your style, a longer interval is probably just fine, but fresh brake fluid is cheap insurance.

**6. Are there any differences between brake fluids? Should I be concerned about mixing different types or different brands?**

Like motor oils, most DOT 3 and DOT 4 brake fluids are compatible with one another and should mix without any problem. However, silicone-based DOT 5 fluids are absolutely not compatible with any DOT 3 or DOT 4 brake fluids and really shouldn't be considered for your application unless your vehicle came with DOT 5 in the first place.

That said, DOT 4 fluids are held to a higher government standard than DOT 3 fluids. In general, the DOT 4 fluids will have higher boiling points and will resist water absorption a bit longer than the DOT 3 fluids, but the down side is that DOT 4 fluids should be replaced on a more regular basis than DOT 3 fluids. Ironically, the very compounds that help to raise their boiling points make them wear out more quickly. Nothing is ever free, is it?

**7. How about DOT 5.1 fluid? Is it better than DOT 3 or DOT 4 fluids?**

DOT 5.1 fluids should mix just fine with DOT 3 and DOT 4 fluids, as they too are made from the same base materials. However, DOT 5.1 fluids (which perform to much higher levels than DOT 3 or DOT 4 fluids) are usually overkill for street-driven vehicles.

**8. I'm thinking about installing cross-drilled rotors. What kind of brake system improvements should I notice?**

Well, unless your truck is using brake pads from the 40s and 50s, not a whole lot. Rotors were first drilled because early brake pad materials gave off gasses when heated to racing temperatures—a process known as "gassing out." These gasses then formed a thin layer between the brake pad face and the rotor, acting as a lubricant and effectively lowering the coefficient of friction. The holes were implemented to give the gasses somewhere to go. It was an effective solution, but today's friction materials do not exhibit the same level of gassing out phenomenon as the early pads.

For this reason, the holes have carried over more as a design feature than as a performance feature. Contrary to popular belief, they don't lower temperatures much at all. In fact, by removing weight from the rotor, the temperatures can actually increase a little under certain conditions. They create stress risers allowing the rotor to crack sooner, and make a mess of brake pads—sort of like a cheese grater rubbing against them at every stop.

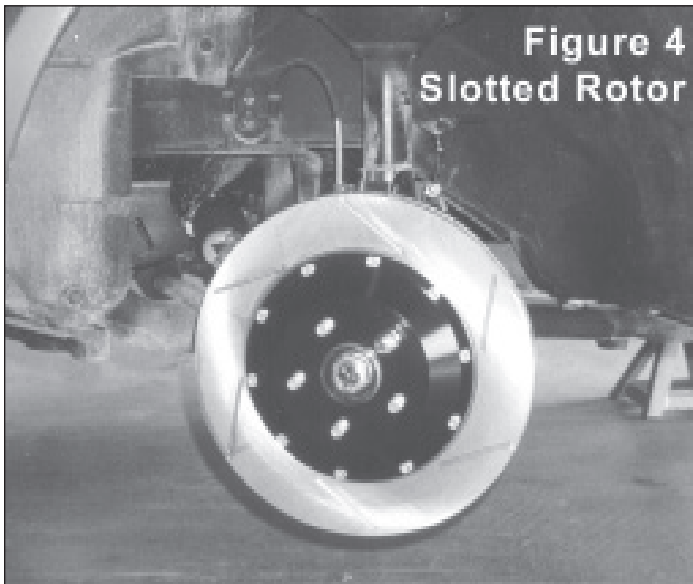
However, they do look cool and can arguably improve initial brake pad bite. If those are reasonable trade-offs, go for it; but don't expect shorter stopping distances or reduced brake temperatures regardless of the marketing hype.

**9. I'm thinking about installing slotted rotors. What kind of brake system improvements should I notice?**

Cutting thin slots (usually only a few mm deep) across the face of the rotor can actually help to clean the face of the brake pads over time. This helps to reduce the "glazing" often found during high-temperature use which can eventually lower the coefficient of friction. While there may still be a small concern over creating stress risers in the face of the rotor, if the slots are shallow and cut properly, the trade-off appears to be worth the benefit.

There are as many slotting designs and patterns as there are brake manufacturers these days (see Figure 4), but the differences are primarily cosmetic. More slots equal more leading edges, but the effect is the same.

As a final note, expect extra dusting and shorter life from your brake pads if you run slotted rotors on the street!



**10. I have noticed that my rotors have a bunch of grooves on the outboard and inboard faces. Is this a bad thing?**

In general, shallow grooves on the face of a rotor are not terminal. They can be caused by debris caught between the pad and the rotor, brief overheating of the rotor face, or voids in the brake pad surface. It's just a natural thing, but be wary of deep scoring or pitting—both are valid reasons for rotor replacement.

**11. I'm thinking about installing stainless steel braided brake lines. Is this a good idea?**

When you get down to it, the only difference between the cool looking stainless steel brake lines and the stock flexible lines are the outer covering (stainless braid versus rubber). The tube that the brake fluid passes through is still nylon, and the fittings at either end are just hollow bolts.

What the stainless lines do provide is increased protection from flying roadway debris and slightly less compliance (expansion) when brake fluid pressure is generated (see Figure 5).



In some applications, this reduction in compliance can be perceived by the driver as a "firmer" pedal, but every application is different (and usually a function of the age of the original lines at the time of replacement). On a big diesel running factory Hydroboost, the improvement in pedal feel will probably be pretty small, but may be noticeable. Don't set your expectations too high and you probably will not be disappointed.

**12. How many times can I turn my rotors before they need to be replaced?**

When determining whether a rotor should be turned or replaced the important factor is not how many times it has been turned in the past, but rather how thick the rotor is in the first place.

Nearly every rotor available (both from the factory and over the counter) has a minimum thickness number cast into the back side of the rotor hat section. This number is the minimum thickness recommended by the manufacturer after the rotor has been turned, not before.

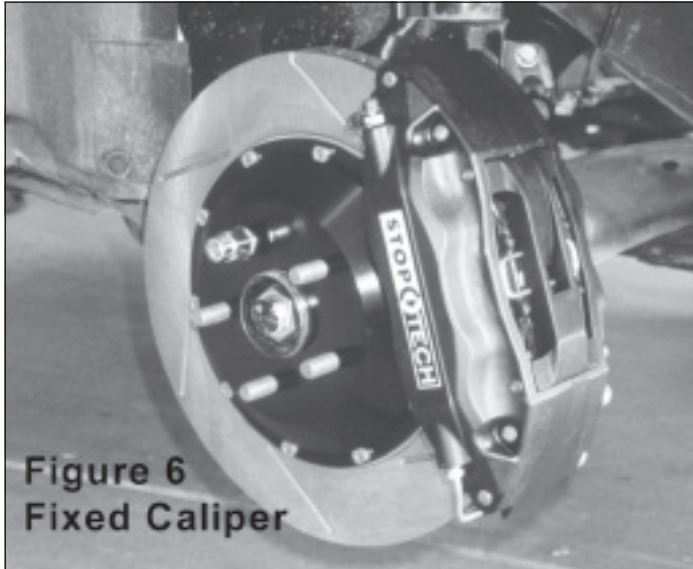
As a rule of thumb, turning a well-used rotor usually results in taking off at least 0.030" to 0.050" of material per side, so be sure to measure beforehand to see if the rotor is even a candidate for turning. If you don't have the tools necessary to measure and make the determination yourself, most auto parts stores will be happy to check them for you.

**13. Are there minimum thickness number for drums as well?**

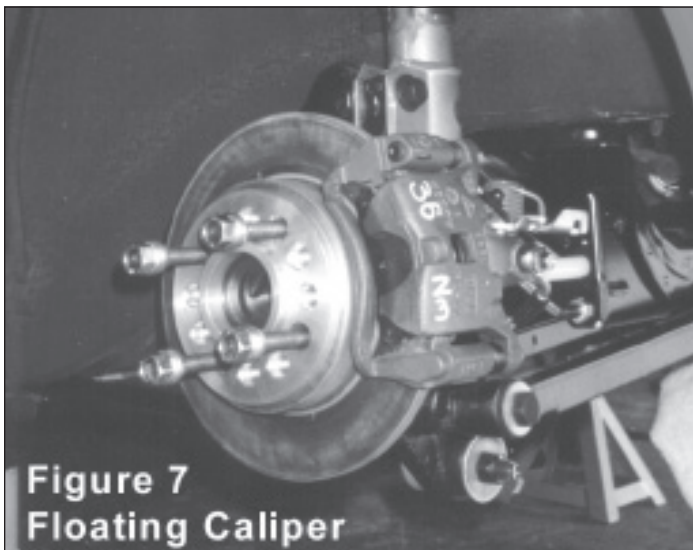
As with rotors, most drums also have a cast-in dimension for thickness after turning. However, because material is removed from the inside diameter of the drum, the number given is a maximum dimension not to be exceeded after turning.

**14. What's the difference between a "fixed" caliper and a "floating" caliper? Is one type better than the other?**

As the name implies, a fixed caliper (see Figure 6) is rigidly attached to some part of the vehicle suspension (the axle housing, a front knuckle, etc.). Because the caliper body is not free to move relative to the rest of the braking system (the rotor in this case), these calipers have pistons on both the inboard and outboard rotor faces, allowing a clamping force to be generated when pressure is applied.



In the floating set-up, an anchor bracket is mounted to the vehicle suspension and the caliper body is free to float axially in the bracket on a pair of slider pins (see Figure 7). This design allows for pistons on the inboard side of the caliper body only. The rest of the clamping force is generated by the reaction force on the caliper fingers (the outboard side of the caliper body) which are pulled against the rotor face as the pistons on the inner face extend outward.



While the fixed type caliper is more efficient in general, floating calipers typically take up less space and are cheaper to manufacture. For this reason, almost every large-volume production truck and car on the road today (including your Ram) utilizes floating calipers.

**15. What is brake pad fade?**

Pad fade (or lining fade) occurs when the materials which make up the brake pad actually begin to vaporize and boil to the pad surface. These gasses then form a nice lubricating layer between the brake pad and the rotor face, effectively reducing the coefficient of friction between the two to near zero. What this means to the driver is that the pedal is quite firm and high in its travel, but regardless of how hard the pedal is pushed, the truck just won't stop. This is generally not considered to be a good thing.

So why does pad fade occur? Heat. All brake pads have a thermal point at which they create these gasses, some naturally higher than others. Your first clue that you are approaching pad fade will be the smell of the pads letting off their gasses. Your next clue will be the inability to stop your truck. Pay attention to the first clue.

**16. What is brake fluid fade? Is it different from brake pad fade?**

Fluid fade also occurs when heat gets out of control, but in this case the brake fluid itself will actually boil in the lines. Because brake fluid as a vapor is much more compressible than brake fluid as a liquid, the driver will get the sensation of the pedal being quite soft and spongy. In extreme cases, the pedal can fall almost to the floor before the truck begins to slow. This also is highly undesirable.

Unlike with pad fade, there are no early warning signs to the driver that things are going downhill fast (no pun intended). However, if fluid fade is encountered it can usually be remedied on the fly by quickly pumping the brake pedal to force more fluid into the system. This should not be mistaken for a long-term solution, but in the heat of the moment (again, no pun intended) it might just save you and your truck.

**17. So how can I avoid both types of fade?**

The best way to avoid pad fade is to invest in brake pads which can take the heat. Fluid fade can be avoided by using a high-quality brake fluid and replacing it on a regular basis. However, in both cases heat is the enemy, so slowing down or reducing your load is always another viable short-term solution.

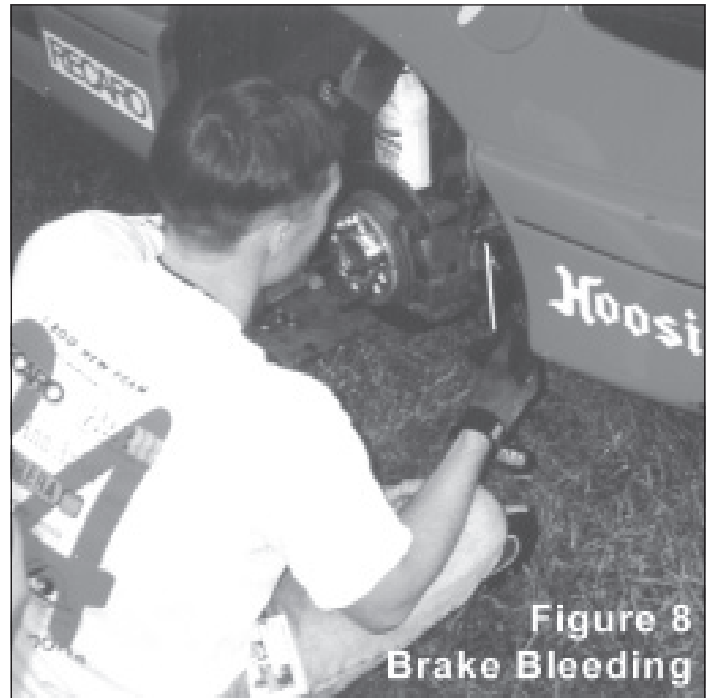
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**18. What is the process for changing my brake fluid? Is it different than what I would do to bleed my brakes?**

This procedure works for both bleeding the brakes and for completely replacing the fluid. The only difference is in the number of times the process is repeated.

1. Begin at the corner farthest from the driver and proceed in order toward the driver. (Right rear, left rear, right front, left front.)
2. Locate the bleeder screw at the rear of the caliper body (or drum brake wheel cylinder). Remove the rubber cap from the bleeder screw. Don't lose it!
3. Place a box-end wrench over the bleeder screw hex. An offset wrench works best since it allows the most room for movement.
4. Place one end of a clear plastic hose over the nipple of the bleeder screw. Make sure it is a tight fit to avoid leaks.
5. Place the other end of the hose into a clear disposable bottle.
6. Place the bottle on top of the caliper body or drum assembly. Hold the bottle with one hand and grasp the wrench with the other hand.
7. Instruct your assistant sitting in the truck to "apply." The assistant should pump the brake pedal three times, hold the pedal down firmly, and respond with "applied." Instruct the assistant not to release the brakes until told to do so.
8. Loosen the bleeder screw with a brief  $\frac{1}{4}$  turn to release fluid into the waste line. The screw only needs to be open for one second or less. (The brake pedal will "fall" to the floor as the bleeder screw is opened. Again, instruct the assistant in advance not to release the brakes until instructed to do so.)
9. Close the bleeder screw by tightening it gently. Note that one does not need to pull on the wrench with ridiculous force. Usually just a quick tug will do.
10. Instruct the assistant to "release" the brakes. Note: do NOT release the brake pedal while the bleeder screw is open, as this will suck air back into the system!
11. The assistant should respond with "released."
12. Inspect the fluid within the waste line for air bubbles.
13. Continue the bleeding process (steps 11 through 16) until air bubbles are no longer present. Be sure to check the brake fluid level in the reservoir after bleeding each wheel. Add fluid as necessary to keep the level at or near the MAX marking. (Typically, one repeats this process 5-10 times per wheel when doing a 'standard' bleed, more if the fluid is being completely replaced.)

14. Move systematically toward the driver—right rear, left rear, right front, left front—repeating the bleeding process at each corner (see Figure 8). Be sure to keep a watchful eye on the brake fluid reservoir. Keep it full!



15. When all four corners have been bled, spray the bleeder screw (and any other parts that were moistened with spilled or dripped brake fluid) with brake cleaner and wipe dry with a clean rag. (Leaving the area clean and dry will make it easier to spot leaks through visual inspection later!) Try to avoid spraying the brake cleaner directly on any parts made of rubber or plastic, as the cleaner can make these parts brittle after repeated exposure.
  16. Test the brake pedal for a firm feel. (Bleeding the brakes will not necessarily cure a "soft" or "mushy" pedal—since pad taper and compliance elsewhere within the system can contribute to a soft pedal. But the pedal should not be any worse than it was prior to the bleeding procedure.)
  17. Be sure to inspect the bleeder screws and other fittings for signs of leakage. Correct as necessary.
  18. Properly dispose of the used waste fluid as you would dispose of used motor oil. Important: used brake fluid should NEVER be poured back into the master cylinder reservoir. Dispose of the fluid as you would motor oil.
- 19. If my brake fluid is below the MAX mark on the fluid reservoir, should I have it topped off?**

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Usually not. Your brake system is designed so that as the brake pads wear, fluid stored in the reservoir is used to backfill the space left by the worn out pad material. When the next time comes to replace the pads, the fluid is then pushed back into the reservoir to start the cycle all over again.

The only time that fluid will actually leave the hydraulic system is if there is an external leak. This too will make the fluid in the reservoir drop, but the right answer is not to keep filling the fluid—you should find the leak and fix it immediately!

If you accidentally top off the fluid when the pads are worn out, or if your friendly service tech does it for you without knowing better, be careful to drain some of the fluid out of the system before replacing your brake pads. If you try to push the pistons back into the calipers to make room for the new pads, you may end up forcing all of the extra fluid out of the reservoir and down your firewall.

## **20. What can I do to my braking system to shorten my stopping distances?**

Remember back from our article in Issue 40—the traction between the tire and the road is the limiting factor in determining your truck's best stopping distance (see Figure 9). Making changes to any part of the braking system may reduce how hard you need to press on the brake pedal to get there, but ultimately it's the tire-to-road interface that governs the relationship.

If you want the shortest distances possible, buy the best tires you can. It's really that simple.



## **21. Why are there twenty-one questions in this article?**

Because everyone writes up a "Twenty Questions" article at some point. We just wanted to go one better.

**James Walker, Jr.**  
TDR Writer

## **BRAKE FLUID EXPOSÉ**

### **Everything You Always Wanted to Know About Brake Fluid (And are probably still afraid to ask)**

by James Walker

Without a doubt, changing brake fluid is at the absolute bottom of most owners' lists of "fun things to do with their trucks." Unfortunately, this mystery fluid is also one of the most vital components of all of your truck's safety systems, yet it can be neglected for years and years and years at a time. Heck, there are some people who would not change their fluid for the life of their truck without even batting an eye.

If you are one of these people, don't worry—help has arrived. Here is everything you will ever need to know about the very lifeblood of your truck's braking system. If you are not itching to run to the garage by the time you are done reading, you might want to check your pulse.

Okay, maybe that comment about checking your pulse was an overstatement, but you get the idea . . .

#### **What exactly does brake fluid do?**

Brake fluid's sole function is to transmit the pressure generated in the brake master cylinder to the four wheel brake assemblies. At the wheel ends, this pressurized fluid energy is ultimately translated into brake torque through another set of piston-based devices—calipers in the case of disc brakes or wheel cylinders in the case of drum brakes.

Now, while that may sound simple and straightforward, one needs to remember the various demands placed on the fluid itself. Just to name a few:

- The fluid must not solidify (freeze)
- The fluid must not vaporize (boil or fade)
- The fluid must be compatible with rubber seals
- The fluid must not be excessively compressible

#### **Temperature extremes**

Because real-world temperatures in North America routinely fall below -40F (and even colder in extreme locations), we have an idea of just how low the freezing point must be if we also want to add in a safety factor. Realistically, brake fluid itself has such a low freezing point that this limit is rarely, if ever, a concern.

High temperature performance, however, is a completely different animal. Not only does the fluid need to be robust to high ambient temperatures (130F and higher in Death Valley, for example), but one also needs to consider that the brakes themselves generate a significant amount of heat during operation. Quite frankly, Death Valley looks like an icebox in comparison.

During heavy driving, hauling, or towing, it is not uncommon to see brake pad and rotor temperatures in excess of 800F. While not all of that heat is inflicted on the caliper, the brake fluid inside can easily experience temperatures in the 300F-400F range with prolonged exposure. Yikes!

Fortunately for us, brake fluid manufacturers have found a way to formulate brake fluids that meet these extreme operating conditions. Unfortunately, these very same fluids have a skeleton in the closet...

#### **Water: the silent, wet enemy**

DOT 3, DOT 4, and DOT 5.1 brake fluids (more on these terms later) are based on glycol ether-based stocks, and as a result are hygroscopic in nature. In plain English, they absorb water like there is no tomorrow. (Conspicuous by its absence from the list above is DOT 5 fluid. Unlike DOT 3, 4, and 5.1, DOT 5 fluid does not naturally absorb any water whatsoever. More on this later.)

When brand new, common brake fluids can have boiling points of well over 400F without really even breaking a sweat. However, if even a minute level of water is adsorbed into the fluid (less than 5% of the brake fluid volume, for example), the boiling point can plummet to less than half of the value when new. For this reason, brake fluids have two advertised boiling points—dry (new) and wet (used).

This is also the reason that brake fluid comes in sealed containers. Once the seal is broken, the irreversible process of water absorption begins. Note also that once you open a new container of fluid you should either use the entire contents or discard the remaining portion. Brake fluid left on the shelf for a few years will degrade rapidly in boiling point performance. Figure 1 shows a typical seal.



**Figure 1 – A typical brake fluid container seal.**

### Why the heck do we use brake fluids that absorb water in the first place?

Believe it or not, one of a brake fluid's most vital characteristics is its ability to absorb water. Yes, you read that correctly—brake fluids absorb water by design and that is really a good thing.

What?

Whether we like it or not, water is everywhere and finds its way into everything. That's just the nature of the beast. Given enough time, even a brand-new sealed brake system will eventually absorb water.

The magic of diffusion allows moisture in the air to permeate microscopic pores in the rubber brake hoses, the nylon master cylinder reservoir, and the various rubber seals in the hydraulic system. Sadly, there is nothing we can do about it, and if left unchecked the water would sit in our brake system and rot it away from the inside out. If you never change your brake fluid, this is exactly what will happen.

Hence the need for brake fluid to absorb this unwanted house guest. Because brake fluid absorbs water into solution, the local concentration levels are typically low enough that corrosion is slowed dramatically. As an added benefit, when exposed to low temperatures the solution state prevents the water from pooling and freezing on its own. While water in brake fluid will certainly increase the solution viscosity at low temperatures, this is much more desirable than having little chunks of ice plugging up the system!

So, the next time you are bleeding your brakes to remove the water-contaminated fluid, don't curse at the automotive gods too cloudily. After all, the fluid was only doing its job.

### DOT Ratings

So, what exactly is the DOT rating telling us? More importantly, what is the DOT rating NOT telling us? A quick look at FMVSS116 (the US Government's regulation for brake fluids, comprised of no less than twenty-two pages of brake fluid minutiae) will tell us all we need to know.

### DOT 3 Fluid

DOT 3 fluids (such as shown in Figure 2) are usually glycol ether-based, but that is not because they are required to be. In fact, FMVSS116 makes no mention whatsoever about the chemical compounding of brake fluids—it simply dictates the fluid physical properties. However, the brake fluid industry has by consensus decreed that glycol ether fluids are the most economical way to meet the requirements, so there you are.

These glycol ether fluids are typically a by-product of the process used to make certain paints and varnishes. By definition, DOT 3 fluids must have a minimum dry boiling point (measured with 0% water by volume) of 401F and a minimum wet boiling point (measured with 3.7% water by volume) of 284F. That's really about all the specification says as far as the average consumer is concerned.

### DOT 4 Fluid

DOT 4 fluids are also glycol ether based, but have a measure of borate esters thrown in for increased immunity to water absorption. Because of this chemistry, the DOT 4 fluid will have a more stable boiling point during the early portion of its life, but ironically once the fluid does actually begin to absorb water, its boiling point will typically fall off more rapidly than a typical DOT 3. By FMVSS116 standards, DOT 4 fluids must have a minimum dry boiling point of 446F and a minimum wet boiling point of 311F.



Figure 2 – Typical garden-variety DOT 3/4 brake fluid.

### Is DOT 4 Better?

Does this make DOT 4 fluids better than DOT 3 fluids? Not always. Remember, the boiling points listed are minimums, and there are DOT 3 fluids out there with higher boiling points than some DOT 4 fluids. The real differentiating factor should be that if you run a DOT 4 fluid you really should change the fluid more often than if you use a DOT 3, if for no other reason than the rapid fall off in boiling point with time.

## DOT 5: A Different Animal

On their own, silicone-based DOT 5 fluids are entirely different animals than DOT 3 and 4 fluids. Their high boiling points—509F dry and 356F wet—make them appear at first glance like just the ticket for severe-duty applications. In addition, they also tend to have much, much lower viscosities, which improves cold weather performance dramatically.

Why not just pour it in and go? One side effect of this chemistry is that there is more “room” for air to fit in-between the individual molecules of brake fluid than in DOT 3 or 4 fluids. Note that we are not talking about big bubbles of air visible to the naked eye, but rather microscopic amounts of air which are finely dispersed (entrained) in the brake fluid matrix.

Now, all fluids have a certain amount of compressibility to start with, but adding even the smallest amount of air into the solution can dramatically increase the amount of elasticity in the system. In the case of silicone-based fluids, air is quite happy to take up residence between the brake fluid molecules, and, as a result, the fluid compressibility goes up. This is felt at your foot like stepping on a big spring. As you can imagine, more air = more spring. For this reason, silicone-based DOT 5 fluids are typically not favored in applications where high brake line pressures are present or when firm brake pedal feel is a critical design target.

Finally, because of the unique chemistry of the DOT 5 fluids, they cannot be mixed with DOT 3, 4, or 5.1 fluids. Think “oil and water.” Because it is relatively impossible to completely purge the system of old fluid when doing a fluid change, pockets of the silicone-based fluid will always remain isolated from the ether-based fluid. This can result in areas of localized water content, or areas of varying boiling points.

Because most modern vehicles come from the factory with DOT 3 or 4 fluids, it is a safe assumption that you should not even consider putting DOT 5 in your truck. In fact, the only production vehicles sold in the US that come from the factory today with DOT 5 fluids are Harley-Davidson motorcycles. Why? Because DOT 3, 4, and 5.1 fluids will mar the fancy paint on these machines if spilled, DOT 5 will not.

## DOT 5.1 Fluid

Historically, DOT 5-level performance (specifically boiling points and viscosity) could only be achieved with silicone-based fluids. However, modern compounding has created glycol ether-based fluids which now meet DOT 5 bogeys in these key areas. Consequently, the DOT 5.1 moniker was created to differentiate between these two very different chemistries, which both meet DOT 5 performance requirements.

In so many words, DOT 5.1 fluids (see Figure 3) are simply DOT 4-type fluids which meet DOT 5 performance requirements. Because of this, they typically can be mixed with DOT 3 or 4 fluids without concern. In some circles, they are even referred to as ‘DOT 4 Plus’ or ‘Super DOT 4’ fluids because they are more similar to a conventional DOT 4 fluid by chemistry than they are to a conventional DOT 5 fluid.



Figure 3 – Typical high-performance DOT 5.1 brake fluid.

While it may not be obvious, the big advantage of the DOT 5.1 fluids is that they contain all of the nifty water-absorbing characteristics of the DOT 3 and 4 fluids while simultaneously providing for very high boiling points and relatively stable viscosity over a wide range of temperatures. The best of all worlds, you could say.

So, what is the downside of the DOT 5.1 fluids? Like most things in life, the good stuff isn't cheap. DOT 5.1 fluids typically cost three to four times as much to manufacture as conventional DOT 4 fluid. There's always a catch, but you get what you pay for.

In summary, the chart in Figure 4 does a good job at comparing the four categories of brake fluid and their respective characteristics.

## Picking the Right Fluid

Ultimately, there is no magic here. However, be forewarned that if you are working your truck hard there are NO fluids which allow you to run indefinitely without periodic bleeding or replacement. The best that a fluid can do for you is provide stable, consistent performance during use; but because all fluids will absorb water over time, all fluids must be bled at some point. It's that simple.

As a rule, feel free to experiment with DOT 3, 4, and 5.1 fluids to find the right brand for your application, but steer clear of DOT 5. Remember, the DOT 5 silicone-based fluids are not miscible (a fancy way of saying compatible) with the ether-based fluids. Leave the DOT 5 stuff for the two-wheel crowd!

The chart in Figure 4 does a good job of comparing the four categories of brake fluid and their respective characteristics. Use it to find the best DOT 3, 4, or 5.1 fluid that fits your budget and is readily available to you. If your fluid never boils, you've arrived—there's your “right” fluid. However, if fluid fade persists, you may have to bite the bullet and pay up the ladder for the next best thing.

| Property                              | DOT 3                 | DOT 4                         | DOT 5             | DOT 5.1                       |
|---------------------------------------|-----------------------|-------------------------------|-------------------|-------------------------------|
| Dry BP (F)<br>@ 0.1% H <sub>2</sub> O | 401                   | 446                           | 509               | 509                           |
| Wet BP (F)<br>@3.7% H <sub>2</sub> O  | 284                   | 311                           | 356               | 356                           |
| Chemical<br>Composition               | Glycol Ether<br>Based | Glycol Ether/<br>Borate Ester | Silicone<br>Based | Glycol Ether/<br>Borate Ester |

Figure 4 – DOT requirement summary table.

James Walker, Jr.

TDR Writer

***Convinced that DOT 5.1 is the ticket for your next brake fluid maintenance? Check out the folks at EGR brakes as they are well known for their extreme-duty brake systems and fluids.***

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## BRAKE BIAS

by James Walker

As you have probably noted in previous pages of the TDR, I regularly glean other automotive and technical periodicals in an on-going search for answers to questions from TDR readers about their trucks.

In one such search a couple of years ago in the pages of Grassroots Motorsports I found an article about brake systems by James Walker, which was so useful I decided on the spot that his presentation of information simply had to be made directly available to TDR readers.

The result was the series we commissioned Walker to write on the mysteries of braking systems appearing in the last four issues: the first to appear was "Brake systems in Plain English" in Issue 40, followed by "Brake Pad Selection" in Issue 41, "Twenty-one Brake Questions" in Issue 42, and "Brake Fluid Exposé" in Issue 43.

The past year has proved the merit of Walker's series on brake systems and demonstrated his ability to convey some highly technical information in very readable style and format.

James' facility in conveying this information is not surprising: he is eminently qualified to instruct us in these arcane matters. While he would not brag about his qualifications, I can boast a little about the extent of his background in brake systems.

His background includes employment at TRW (formerly Kelsey-Hayes), General Motors, Bosch, Ford Motor Company, and presently Delphi Corporation. When spare time allows, he serves as a consultant to StopTech, a high-performance brake systems company. James also participates in SCCA sports car club racing. In 2004 he will serve as an instructor at the Society of Automotive Engineers conferences. We should also watch for his articles on brake and suspension systems to appear in an upcoming special edition of Car & Driver magazine.

The four installments of James' series seemed so nearly exhaustive that at first I was at a loss for a topic he should address in this issue of the TDR. But my puzzlement was solved by the editors of Grassroots Motorsports who, apparently, were one jump ahead of me. In their January '04 magazine they had James write an article on front-to-rear brake bias and brake proportioning valves. *Voilà* (I said to myself in my best broken French), let's have James write two articles for the TDR covering brake balance (bias) and brake proportioning valves.

In suggesting to James a subject for his contribution to this issue of the TDR, I sent him a letter from a TDR member outlining the reader's experiences with a brake system.

That letter, suggestively titled "The problem with the front brakes may be the rear brakes," covered steps in adjusting the truck's height-sensing brake proportioning valve. Because the letterwriter was continuing in his experiment to improve feel in the brake system, I chose not to publish it until I had better understanding of hardware and dynamics. James' next two articles in this issue should provide us that understanding.

In this article covering front-to-rear brake bias, James will add a new wrinkle to the available traction equation-weight transfer. So James, the balance (pun intended) of the article is yours.

## WHY BALANCE (BIAS) MATTERS

Long, long ago in a magazine far, far away (actually, it was just a year ago in Issue 40, but who's counting?), a few renegade brake engineers rallied together to bring forward the following message:

*"You can take this one to the bank. Regardless of your huge rotor diameter, brake pedal ratio, magic brake pad material, or number of pistons in your calipers, your maximum deceleration is limited **every time** by the tire to road interface. That is the point of this whole article. Your brakes do not stop your truck. Your tires stop the truck. So while changes to different parts of the brake system may affect certain characteristics or traits of the system behavior, using stickier tires is ultimately the only sure-fire method of decreasing stopping distances."*

However, there's more to the story. Yes, the tires stop the truck, but improper front-to-rear bias (brake balance) can make a complete mess out of even the best components.

## THERE'S ALWAYS A "BUT", ISN'T THERE?

As braking force is continuously increased, one end of the truck will eventually break traction (skid). If the front wheels lock up and turn into little piles of molten rubber first, we say that the truck is "front biased," as the front tires are the limiting factor for deceleration. In the not-so-desirable situation where the rear tires are the first to lock, we say that the truck is "rear biased," but the driver would probably have a few more choice adjectives to add as the back of the truck tried to change places with the front end. However, in either case one end of the truck has given up before the other, thus limiting the ultimate deceleration capability of the truck.

In a racing scenario, the car with perfectly balanced brake bias will be the last one to hit the brakes going down the back straight prior to entering the next corner. By distributing the braking forces so that all four tires are simultaneously generating their maximum deceleration, stopping distance will be minimized and our brake system components will be operating at their maximum efficiency.

All that said, once the braking system has achieved its perfect balance, it is still up to the tires to generate the braking forces. It's still the tires that are stopping the truck. However, a poorly designed braking system can lengthen stopping distances significantly, expensive sticky tires or not.

## SO WHY IS BRAKE BIASING NECESSARY?

From Issue 40, "Brake Systems in Plain English," recall that the maximum braking force that a particular tire can generate is theoretically equal to the coefficient of friction of the tire-road interface multiplied by the amount of weight supported by that corner of the car or truck. For example, a tire supporting 500 pounds of vehicle weight with a peak tire-road coefficient of 0.8 (a typical street tire value) could generate, in theory, 400 pounds of braking force. Throw on a good race tire with a peak coefficient of 1.5, and the maximum rises to 750 pounds of braking force. More braking force means higher deceleration, so we again see the mathematical benefits of a sticky race tire.

On the other hand, if our race tire was now supporting only 300 pounds, the maximum force would drop from 750 pounds of braking force to 450 pounds of braking force—a reduction of 40%.

Since the amount of braking force generated by the tire is directionally proportional to the torque generated by the calipers, pads, and rotors, one could also say that reducing the weight on the tire reduces the maximum brake torque sustainable by that corner before lock-up occurs. In the example above, if an assumed 700 ft-lb. of brake torque is required to lock up a wheel supporting 500 pounds, then only 420 ft-lb. (a 40% reduction) would be required to lock up a wheel supporting 300 pounds of vehicle weight.

At first glance, one could surmise that in order to achieve perfect brake bias you could just:

1. Weigh the four corners of the truck
2. Design the front and rear brake components to deliver torque in the same ratio as the front-to-rear weight distribution
3. Be happy in your newfound brake utopia

In other words, for a rear-wheel-drive race car with 50/50 front/rear weight distribution it would appear that the front and rear brakes would need to generate the same amount of torque. At the same time, it would look like a production-based unloaded truck with a 60/40 front/rear weight distribution would need front brakes with 50% more output (torque capability) than the rears because of the extra weight being supported by the nose of the truck when unloaded.

Like most things in life, though, calculating brake bias is not as simple as it may appear at first glance. Designing a braking system to these static conditions would neglect the second most important factor in the brake bias equation – the effect of dynamic weight transfer during braking.

## THE EVER-PRESENT WEIGHT TRANSFER PHENOMENON

I'll apologize in advance to TDR readers who may expect that we would use a truck for this example. Unfortunately, this article was originally crafted for a slightly different audience, but rest assured that the same laws of physics and weight transfer apply equally to both race cars and diesel trucks.

That said, let's assume we have a 2500 pound car with a 50/50 static weight distribution. If we are concerned only with the vehicle at rest, it's easy to determine the weight on each wheel. We just need to find some scales and weigh it. The sum of the front corner weights is equal to the front axle weight (1250 pounds), and the sum of the rear corner weights is equal to the rear axle weight (also 1250 pounds). The weight of the vehicle is of course equal to the sum of the two axle weights (our original 2500 pounds), and this weight can be thought of as acting through the vehicle's center of gravity (CG). Figure 1 sums it up nicely.

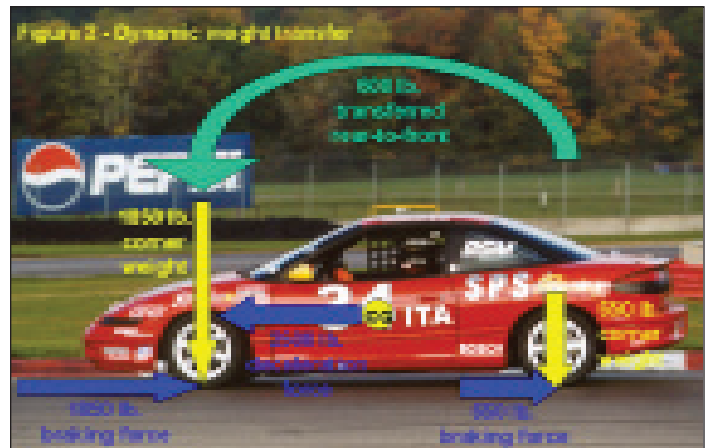


Note that when at rest, there are no horizontal (left or right) forces acting on the vehicle. All of the forces are acting in a vertical (up and down) direction. But what happens to the vehicle when we start to apply forces at the tire contact patch to try to stop it? Let's find out.

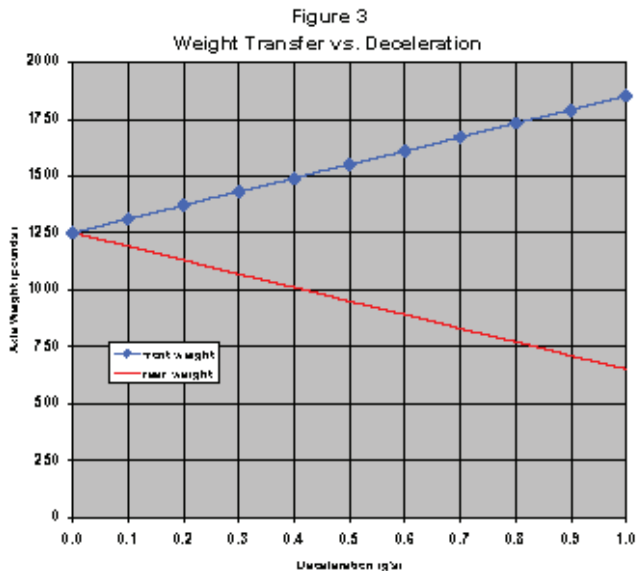
During braking, weight is transferred from the rear axle to the front axle. As in cornering, where weight is transferred from the inside tires to the outside tires, we can experience this effect on our bodies as we are thrown against the seat belts. Consequently, we now need to add several more arrows to our illustration, but the most important factor is that our CG now has a deceleration force acting on it.

Because the deceleration force acts at the CG of the vehicle, and because the CG of the vehicle is located somewhere above the ground, weight will transfer from the rear axle to the front axle in direct proportion to the rate of deceleration. In so many words, this is the effect of weight transfer under braking.

This deceleration force is a function of a mechanical engineer's most revered equation,  $F=ma$ , where **F** represents the forces acting at the tire's contact patches, **m** represents the mass of the vehicle, and **a** represents the acceleration (or in our case, deceleration) of the vehicle. But enough of the engineering mumbo-jumbo, just have a look at these additional factors in Figure 2.



In Figure 3 (the beginning of what we call a “fishbone diagram”—more on this later), we see how our 2500 pound vehicle with 50/50 weight distribution at rest transfers weight based upon deceleration. Under 1.0g of deceleration (and using some typical values for our vehicle geometry) we have removed 600 pounds from the rear axle and added it to the front axle. That means we have transferred almost 50% of the vehicle’s initial rear axle weight to the front axle!



At this point, the brake system we so carefully designed to stop the vehicle with a 50/50 weight distribution is going to apply too much force to the rear brakes, causing them to lock long before we’re getting as much work as we could out of the front brakes. Consequently, the driver is going to get a white-knuckle ride because he creates more tire slip in the rear than the front, *and* it’s going to take longer for him to stop because the front tires are not applying as much force as they could be.

### SO WHAT INFLUENCES BRAKE BIAS?

If we look at the equations we have developed, we see that all of the following factors will affect the weight on an axle for any given moment in time:

- Weight distribution of the vehicle at rest
- CG height—the higher it is, the more weight gets transferred during a stop
- Wheelbase—the shorter it is, the more weight gets transferred during a stop

We also know from fundamental brake design that the following factors will affect how much brake torque is developed at each corner of the vehicle, and how much of that torque is transferred to the tire contact patch and reacted against the ground:

- Rotor effective diameter
- Caliper piston diameter
- Lining friction coefficients
- Tire traction coefficient properties

It is the combination of these two functions—braking force at the tire versus weight on that tire—that determine our braking bias. Changing the vehicle height, wheelbase, or deceleration level will dictate a different force distribution, or bias, requirement for our brake system. Conversely, changing the effectiveness of the front brake components without changing the rear brake effectiveness can also cause our brake bias to change. The following tables summarize how common modifications will swing front-to-rear bias all over the map.

#### Factors that will increase front bias

- Increased front rotor diameter
- Increased front brake pad coefficient of friction
- Increased front caliper piston diameter(s)
- Decreased rear rotor diameter
- Decreased rear brake pad coefficient of friction
- Decreased rear caliper piston diameter(s)
- Lower center of gravity (i.e. lowered truck)
- More weight on rear axle (i.e. loaded)
- Less weight on front axle
- Less sticky tires (lower deceleration limit)

#### Factors that will increase rear bias

- Increased rear rotor diameter
- Increased rear brake pad coefficient of friction
- Increased rear caliper piston diameter(s)
- Decreased front rotor diameter
- Decreased front brake pad coefficient of friction
- Decreased front caliper piston diameter(s)
- Higher center of gravity (i.e. lifted truck)
- Less weight on rear axle (i.e. unloaded)
- More weight on front axle
- More sticky tires (higher deceleration limit)

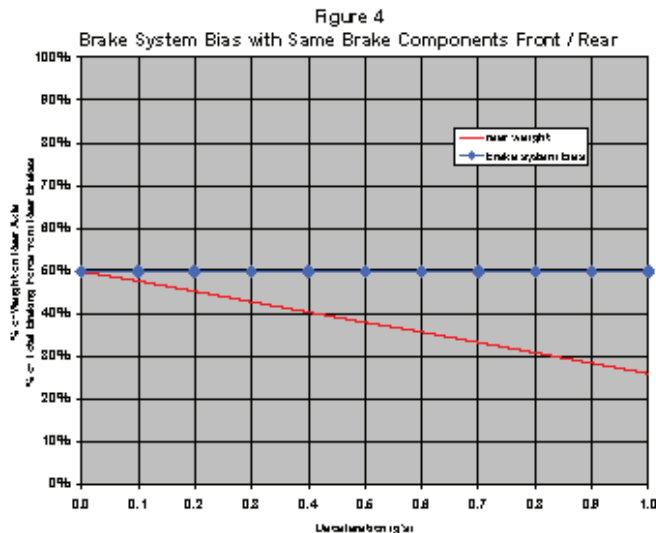
### PERFECTLY BALANCED, IN THEORY

Wow, look at all of the changes that an owner can effect and not even realize that he or she is tinkering with the vehicle’s front-to-rear brake bias! And, we didn’t even touch on other factors such as changes in the weather or road conditions (i.e., factors that can influence the total available tire traction).

While we can do calculations to determine what the optimum front-to-rear brake bias should be under all conditions, the difficult part is creating a brake system that can actually keep up with all of this.

A race car driver has it a little easier than those of us driving trucks in the real world. If he knows what his maximum deceleration capability is due to the tires he’s using, he can tune his brake system for that specific deceleration level. The good part is, if he tunes his vehicle for a 1.5g decel condition, because of the way weight transfer works, his car will be more front-biased in lower traction conditions, such as rain.

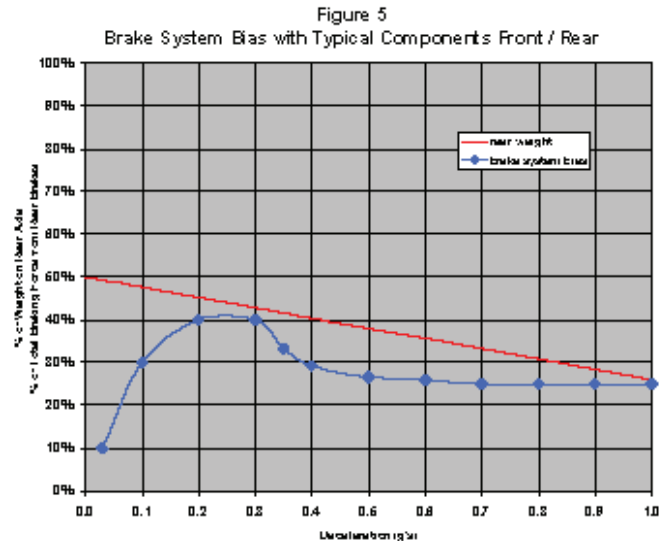
Back to the “fishbone diagram” mentioned earlier. Figure 3 shows front and rear axle weight versus deceleration of the vehicle. Now, let’s look at it as a percentage of the total vehicle weight. We can add on top of this chart the front-to-rear balance of the brake system. For example, if we use the exact same brake components at the front and rear axles of the car, they will each perform 50% of the braking, and the chart will look like Figure 4.



Evaluating this chart, we see that the vehicle will always be rear-biased. That is, the rear brakes will always be applying more force at the tire contact patch than the weight of the rear axle can sustain. This vehicle will always lock the rear brakes before the front. Not so good.

Most trucks, however, have brakes at the rear that are smaller than the front. There are a lot of reasons for doing this, and one of them is to help provide the correct brake bias. Also, most trucks have a proportioning valve which limits the amount of brake pressure seen at the rear brakes. If we look at the same chart with a more realistic braking system (one that takes into account these effects), it might look like the chart in Figure 5.

Perfect brake bias is obtained when the front-to-rear balance of the brake system exactly matches the front-to-rear weight balance of the vehicle. Looking at our typical brake system chart, we see how difficult this is to do. However, if we’re trying to optimize a brake system for a particular deceleration level, it becomes much easier. We can tune the system so that the two lines cross (or come close to it) at the deceleration level the vehicle will be operating at most often. This is easy for a racing vehicle which typically operates at one fixed deceleration level. But, for the rest of us, this is almost impossible to achieve, because a truck driven on the street doesn’t always operate at one deceleration level. (If yours does, you probably don’t get too many repeat passengers!) Compromises, compromises...



And here’s a free tip—effects of compromised brake bias on the street not only include sub-optimal stopping distances, but also include sub-optimal brake pad life. If a truck is too heavily front-biased in the deceleration range it typically operates in, it will wear front pads more quickly due to the fact that the rear brakes aren’t doing as much of the stopping work as they could be. However, the rear brake pads will probably last forever . . . sounds familiar, doesn’t it?

## PERFECTLY BALANCED, IN PRACTICE

Brake bias can be measured in several ways. One method—the way the auto manufacturers do it—is to actually mount wheels on the vehicle that are equipped with strain gauges, so that the actual torque at each wheel can be measured throughout a stopping event. Analysis of the vehicle deceleration data combined with the measured torque values and knowledge of the vehicle parameters mentioned above (wheelbase, CG height, weight on each axle at rest) allow us to calculate brake bias for that particular event. This is the most precise method of measuring brake bias. However, there are simpler and cheaper methods that can be just as effective.

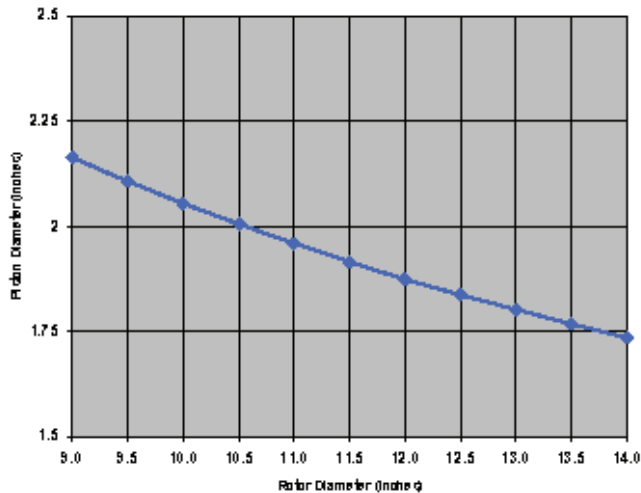
We know where most truck manufacturers tune brake bias—they like our trucks to be front-biased in all conditions achievable by the tires offered on the vehicle. This helps to ensure vehicle stability under braking by the mass public. If we measure stopping distance of the vehicle as delivered from the showroom floor, we have a good benchmark for a vehicle with a 5% to 10% front brake bias.

Now, if we make changes to the truck that can affect brake bias and re-measure stopping distance, we can tell immediately if we have taken a step in the wrong direction. For example, it is not uncommon to install more aggressive front brake pads (which will make the truck even more front biased) and see stopping distances go up 5% or more.

The most dramatic front-bias impacts are usually brought about by brake upgrades which are not properly matched to the intended vehicle. Any time that a bigger front rotor is installed, there is a simultaneous need to decrease the effective clamping force of the

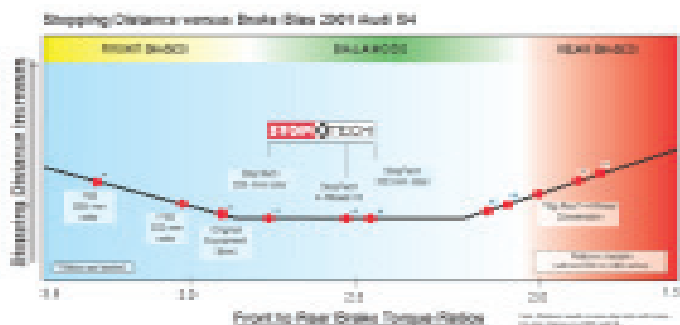
caliper (installing smaller pistons is the easiest method) to offset the increased torque created by larger rotor effective radius. The objective is to maintain a constant amount of brake corner output (torque) for a given brake line pressure as Figure 6 illustrates.

**Figure 6**  
**Rotor Diameter vs. Piston Diameter For Equal Output**



Unfortunately, too many junkyard swaps do not take this factor into account, and those poor trucks end up with both bigger rotors and larger pistons, which serve to drastically shift the bias even more forward. While rock-solid stable under braking, stopping distances will go *up* dramatically.

As Figure 7 illustrates (again, sorry for the non-truck data), every vehicle has a “sweet spot” for brake bias which will generate the shortest stopping distances possible. Typically, the auto manufacturers design their trucks to be 5% to 10% more front-biased than optimum for maximum deceleration, but they provide enhanced brake stability in return, and that’s not a bad trade-off for the public at large.



The flip side can be seen by making changes to increase the amount of rear bias. Because the truck manufacturers leave a tiny (and we mean tiny) bit of wiggle room in their designs, it is usually possible to make small changes to increase rear bias and end up with shorter stopping distances than stock. Keep in mind, however, that there is only so much of this wiggle room to play with. After a point, increased rear bias will make the truck unstable under hard braking and will consequently drive the stopping distances through the roof.

## WHAT ABOUT TRUCKS EQUIPPED WITH ABS?

Anti-lock braking systems can throw yet another factor into the bias equation. While on the surface it may look like ABS would mask some of the effects of compromised brake bias, it is certainly not a cure-all for bias gone bad.

Under full-tilt, stop-the-truck-right-now braking, ABS attempts to cycle all four wheels at their peak traction levels, regardless of the mechanical bias relationship in the braking system. Because ABS will not allow any of the wheels on the truck to lock, balance is naturally maintained and stability is ensured for the braking event.

However, bias can still rear its ugly head on trucks equipped with ABS. Specifically, your truck as delivered by the factory is calibrated to enter ABS under a certain set of dynamic conditions, some of which can be influenced by brake bias. While ultimate stability is not at stake, compromised bias can trigger ABS entry conditions more frequently, as the ultimate deceleration threshold just before ABS control is now lower.

What this means to the driver is that ABS could be more susceptible to false activations or nuisance cycling. This is more of an annoyance than a safety concern under most scenarios, but does anyone really want his truck to be cycling the ABS every time they hit the brake pedal? Didn't think so.

And while we are at it, we should also not forget the impact to brake pad life which comes with compromised bias, ABS equipped or not.

So, while ABS may be able to mask some level of instability under maximum ABS braking, it certainly is not a silver bullet for compromised bias. Even ABS-equipped trucks need to be designed with proper brake bias.

## THE MORAL OF THE STORY

As you go about modifying your truck, be aware that changes in the braking system as well as changes in the truck's ride height, weight distribution, or physical dimensions can swing brake bias all over the place. The only sure-fire way of knowing if your final bias has been optimized is to measure stopping distance both before and after your modification(s).

In summary, your tires certainly still stop the truck, but if your bias is out in left field, you might not be able to use everything they have to offer. Your braking system is just that—a system—and keeping an eye on brake bias effects during modification will go a long, long way toward efficient brake system operation.

In the next issue of the TDR we will delve into what is probably the most misunderstood and misused component of the braking system—the proportioning valve. While some may view this device as another bias cure-all, there is more to the story that needs to be shared before one goes fiddling around under the truck. Stay tuned!

**James Walker, Jr.**  
**TDR Writer**

## THE MYSTERIOUS PROPORTIONING VALVE

by James Walker

### A horribly misunderstood, misused, and misnamed brake system component

In Issue 44 we discussed the glory of front-to-rear bias, or brake balance, and how its optimization could lead to better braking performance. However, one critical factor in establishing bias—the proportioning valve—was left out of the discussion. After all, one can only take so much of this brake talk in one sitting.

That said, we are back to fill you in on the intricacies of just how brake torque is proportioned to the front and rear of the vehicle. More importantly, we hope that you take away the understanding that adjustment of the typical pickup truck height-sensing proportioning valve can do more harm than good. Because such an adjustment is not magic, there are plenty of opportunities to throw the system into disarray without even knowing it.

#### Proportioning valve basics

Let's get this out of the way right now—when it comes to boring truck parts, the proportioning valve must be sitting towards the top of every enthusiast's list.

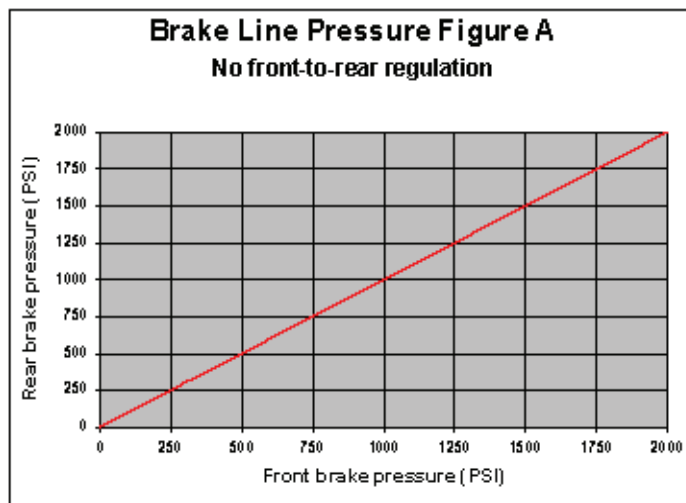
<Pause>

Okay, that's better. Now before everyone throws brake design to the wind in the hopes of fixing everything with the magic proportioning valve, let's take a quick look into these devices and their related mechanical siblings. While a properly designed and used proportioning valve can put the finishing touches on a properly designed and installed brake system, they should not be thought of as a one-stop, fix-o-matic for brake balance disasters.

In general, there are three ways to deal with rear brake pressure—leave it alone, make it proportional to the front brake pressure, or control it in such a way that these two concepts are combined.

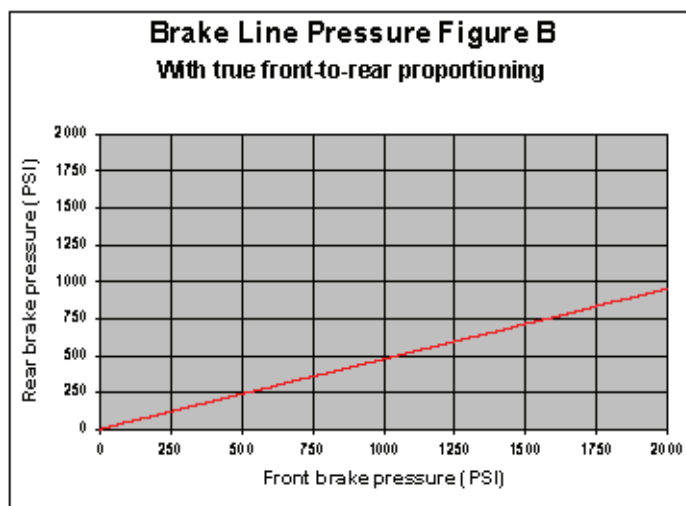
#### Concept 1: Leave it alone

If no device at all were used to modify the rear brake pressure, the front brake pressure and rear brake pressure would always be equal. This relationship can be seen in Figure A. Theoretically this equation would be the easiest way to deal with the pressure, but in order to prevent rear bias under all conditions the rear brake itself would need to be absolutely tiny. As you can imagine, this is not a realistic solution, but we have included it for sake of comprehensiveness.



#### Concept 2: Rear pressure proportioning

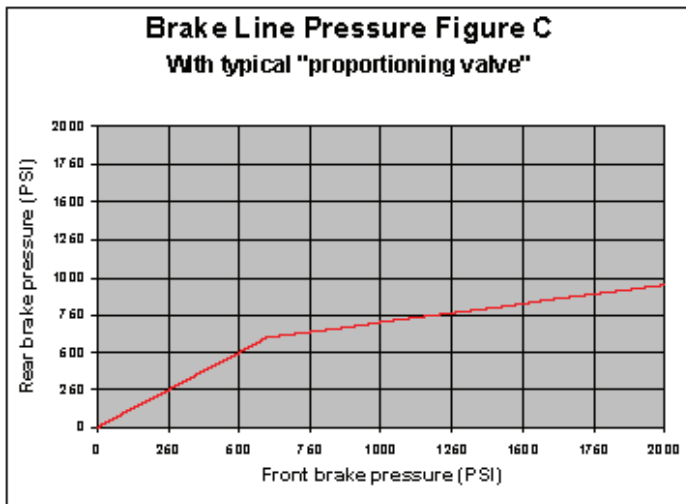
True proportioning would result in rear brake pressures being linearly proportional to front brake pressures under all conditions. This type of pressure regulation is certainly possible to achieve, but normally it requires tandem master cylinders and an adjustable balance (or bias) bar—the same setup found on nearly every purpose-built racing car today. This relationship can be seen in Figure B. The proportioning ratio can be achieved through either master cylinder piston diameter selection or through the adjustment of a mechanical reaction linkage which connects the two master cylinders (the bias bar). Ironical as it may seem, proportioning valves cannot provide this kind of control, for they are not purely proportional devices as their name would imply.



Because of the complexity involved with a dual-master cylinder set-up, this type of proportioning is rarely—if ever—found on passenger cars, and certainly not on modern trucks.

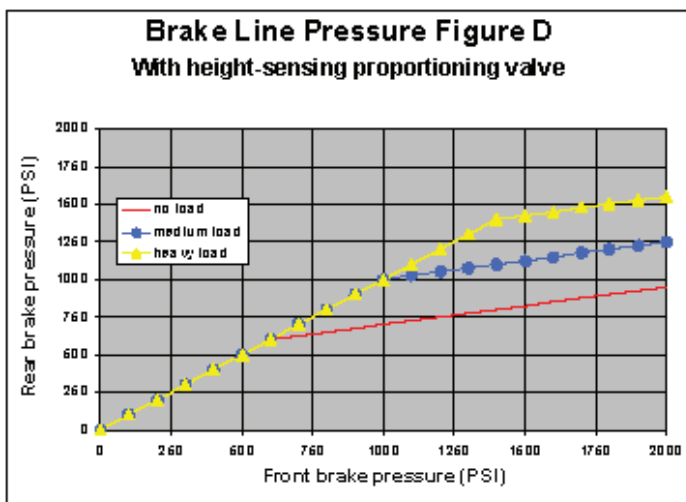
## Combining concepts: The brake system proportioning valve

Proportioning valves (perhaps more accurately referred to as “braking force regulators” or “brake pressure regulating valves”) provide a combination of the control found in Figures A and B. Up to certain pressures, these valves allow equal pressure to both the front and rear brakes (see Figure A). However, once a preset pressure point is reached (600psi in the example) the rear brake pressure continues to build, but at a slower rate (or slope) than the front brake pressure. Figure C displays this quite clearly.



Because of their compact size and relatively low cost, these devices can be found on nearly every vehicle requiring rear brake pressure reduction to achieve optimum brake bias. Pickup trucks fall neatly into this category.

The Dodge Ram truck’s proportioning valve goes one step farther, however, as the kneepoint on the graph above varies with the amount of weight in the bed. In effect as the weight in the bed increases, a linkage between the axle and the frame is compressed. This linkage acts on a cam inside the proportioning valve to increase the preload on the proportioning valve spring. The end result is that more rear braking (bias) is allowed as weight is added to the bed, helping to take advantage of the increased traction now available at the rear tires. Figure D illustrates this relationship quite clearly.



## So, how can one adjust the proportioning valve?

Believe it or not, in nearly all cases the OEM valves are well matched to the original brake system and should not be tampered with, as there are no parts inside that are able to be modified by ambitious owners. Unfortunately, they are externally adjustable, so the temptation to tinker is right there in front of us!

One point to ponder is that because they are a mechanical device, proportioning valves must be designed as a best compromise for use under all conditions. High speed, low speed, fully loaded, and empty-bed scenarios must all be evaluated and figured into the proportioning valve design.

Of course if you have modified your truck in a way that impacts front-to-rear bias you might be standing out in left field! From our bias article in Issue 44, we will bring forward again the lists of modifications which can influence front-to-rear bias.

### Factors that will increase front bias

- Increased front rotor diameter
- Increased front brake pad coefficient of friction
- Increased front caliper piston diameter(s)
- Decreased rear rotor diameter
- Decreased rear brake pad coefficient of friction
- Decreased rear caliper piston diameter(s)
- Lower center of gravity (i.e. lowered truck)
- More weight on rear axle (i.e. loaded)
- Less weight on front axle
- Less sticky tires (lower deceleration limit)

### Factors that will increase rear bias

- Increased rear rotor diameter
- Increased rear brake pad coefficient of friction
- Increased rear caliper piston diameter(s)
- Decreased front rotor diameter
- Decreased front brake pad coefficient of friction
- Decreased front caliper piston diameter(s)
- Higher center of gravity (i.e. lifted truck)
- Less weight on rear axle (i.e. unloaded)
- More weight on front axle
- More sticky tires (higher deceleration limit)

## Proportioning modifications

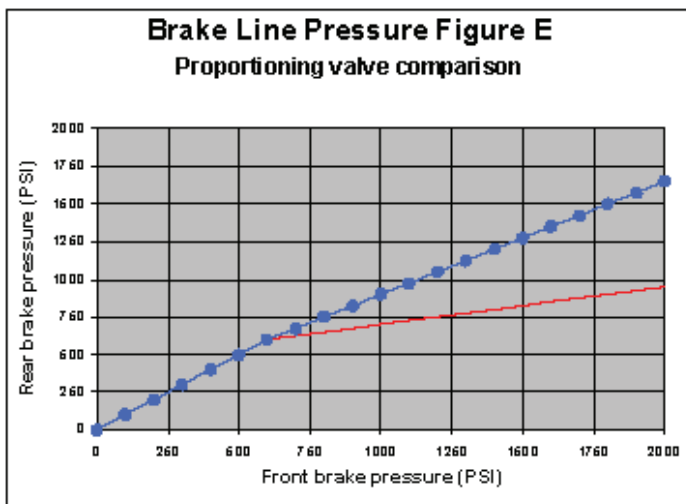
We could start this section by clearly stating that you should not modify your proportioning valve. But, what fun would that be? In all seriousness, making changes to the proportioning valve to affect brake bias should be left to those with the proper tools and measurement devices, but if you have tweaked your truck beyond recognition, this may be your only solution to restore a sense of proper bias to your braking system.

We'll start here with three of the most basic rules regarding proportioning valve installation and selection:

1. If you have the deeply-rooted need to install your own adjustable proportioning valve, be advised that they should NEVER be installed if the factory unit is still in place. Proportioning valves in series with one another can do nasty, unpredictable things!
2. If you have the deeply-rooted need to install your own adjustable proportioning valve, be advised that they should NEVER be installed in-line to the front brakes. The effect would be to make your truck rear-biased before you could say "rear skid, out-of-control." Front brake line pressure should always be left alone—only the rear pressures should be considered for proportioning.
3. In all cases, the basic brake system balance needs to be close to optimum to start with. This is the only way that a proportioning valve can be effectively utilized.

## Proportioning valve selection

If we have not scared you off to this point, maybe this will. Selecting the correct adjustable proportioning valve for your truck entails not only selecting the proper point at which slope limiting begins (the kneepoint), but also selecting the proper rate at which rear brake line pressure builds after that point. Nearly every adjustable proportioning valve on the market today has an adjustable knee point (the point at which the rear brake line pressure begins to be controlled), but a fixed slope (the rate at which it builds beyond the knee point). One parameter is adjustable, but both are critical to system performance. Note that in Figure E the two curves have the same knee point, but the slopes vary greatly.



So how does one select the right kneepoint and slope? Without the test and measurement resources of a major automotive manufacturer, it's next to impossible to say. Of course, you could trial-and-error your way into a situation that you believe to be appropriate, but without testing under all conditions of loading, speed, and road conditions there might be one rear-biased operating condition just waiting to bite you.

## Electronic proportioning: No tampering allowed

As a small sidebar to this discussion of the mechanical proportioning valve, there is a movement afoot to replace the proportioning valve function with the hardware performing the ABS function. While this is not yet the norm, one can predict with reasonable certainty that the trend will continue.

Based on information gathered from the four ABS wheel speed sensors, the Dynamic Rear Proportioning (DRP) algorithm calculates the front-to-rear slip ratio of the four tires. Then, given preset thresholds and parameters, the ABS hardware can intervene and modify the brake pressure going to the rear wheels automatically.

Because DRP is based on actual wheel slip and not on brake line pressure, this type of rear proportioning is more flexible and adaptable to modifications one might make to their truck. It is also less expensive, as the OEM can now remove the mechanical proportioning valve from the truck and replace its function with other hardware already on board.

Naturally, the OEM does not want owners fiddling with their front-to-rear proportioning, and as a result there is no way for the enthusiasts to reprogram DRP to suit their desires. Of course, if the truck's original front-to-rear bias is intact in the first place, there is no need to reprogram anyway.

## So what's the final answer?

In summary, there is more to the proportioning valve than meets the eye. You should make every attempt to plan and select any brake modification carefully so that you are able to retain and reap the benefits of the stock proportioning valve. In other words, pay attention to (and don't stray too far from) the factory bias in the first place and you will be ahead of the game.

If for other reasons you are forced to scrap the stock unit and replace it with an aftermarket unit, be advised that selection and adjustment are not for the uninitiated. While there is more than one way to achieve optimum balance at the point of maximum deceleration, without the right amount of know-how you might be making compromises under partial braking conditions that were not present with the factory hardware.

**James Walker, Jr.**  
TDR Writer

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## BRAKE UTOPIA

by James Walker

Quite simply brake vibrations are never a good thing. In fact, a common saying in the brake industry is, "The best brake system is an invisible brake system." Let's try to understand why this can sometimes be difficult to achieve.

You press the brake pedal and your truck slows down. There's no squealing, no shaking, and no vibration. You have arrived at brake utopia.

Unfortunately, brake utopia can sometimes be in another area code.

Pick your favorite brake system malady: brake roughness, pulsation, shudder, hot judder, shake, vibration, or the all-time favorite, rotor warping. To the brake engineer these all have slightly different meanings, but to the average consumer they are all simply a problem that has to be addressed.

Few vehicle problems are as annoying as a problematic brake system. While usually not a detriment to brake system effectiveness at first, none of these conditions can be considered desirable; and, if ignored long enough they can have legitimate performance impacts.

So what causes these conditions, and what can be done to prevent them in the first place? We'll get there, but first we should briefly review what we learned about brakes back in Issue 40.

### The Brakes Don't Stop the Truck!

What does the brake system do? The brake system's primary responsibility is to convert the kinetic energy of the truck in motion into thermal energy, or heat. If there is available tire traction (tire-to-road friction) the truck certainly may decelerate, but the brakes do not stop the truck. That's the job of your tires.

No tire traction, no tire force, no deceleration. Hello, tree. Thud!



Regardless of how large, colorful, or sexy your braking system components, it's still the tires that stop the truck!

If we look in more detail at the brake pad and rotor interface, we discover that this is where most of the energy conversion takes place. It is the friction between the brake pad and the spinning rotor that creates heat while simultaneously building torque in the rotating brake parts. Over the next few paragraphs we will be dissecting this dynamic interface.

As the saying goes, you paid for the whole seat, but you'll only need the edge!

### The Two Types of Friction

Who takes the time to worry about how the stationary brake pad and the spinning rotor generate friction? Odds are this question has never passed through your mind, but it is paramount to understanding brake vibrations.

Brake pads engage in two distinctly different types of dynamic friction: abrasive friction and adherent friction. The details should be left to the PhD community, but in general the two modes operate as follows:

In the abrasive mode, friction is generated as a result of interference between the microscopic high and low spots on the brake pad face and the spinning rotor. In very simple terms, this is similar to holding a block of wood on a belt sander. As the high and low spots are slowly machined away (much slower than the wood on the belt sander, of course), this breaking of molecular bonds creates a force which resists the rotation of the rotor. It also heats up the materials involved. Breaking molecular bonds has a tendency to do that.

Presto! We have converted kinetic energy into thermal energy by breaking a bunch of molecular bonds. Not too surprisingly, this is the mode that most people naturally envision when asked to explain how brake pad friction operates.

Adherent friction is quite different in nature. In the adherent mode, pressure and temperature collaborate to deposit a thin layer of brake pad material, or a transfer layer, on the rotor face. Subsequently, as the caliper squeezes the brake pads against the rotor, the pads contact the transfer layer, not the rotor itself.

As the pressure increases, molecular bonds are then very quickly formed between the similar materials of the brake pad and the transfer layer. Just as quickly, however, those very same bonds are broken as the rotor continues to move relative to the brake pad. As a result, heat is generated and the brake pad material wears away.

In summary, abrasive friction can be found between the brake pad and the rotor itself, slowly wearing away both materials, breaking bonds, and generating heat and torque in the process. With adherent friction, however, the rotor never actually wears. Because all of the bonding-breaking action is occurring between molecules of the brake pad material, only the pad itself wears away over time.

### But Wait, There's More!

Although we have talked about abrasive friction and adherent friction as if they were mutually exclusive from one another, all brake pads operate in both modes, and sometimes simultaneously. Typically most pads will operate in a primarily abrasive mode when they are cold and will then transition to an adherent mode as the brake temperature increases. This is why some brake pads (for example, many racing brake pads) require warming up before they will be operating properly—they need to “go adherent” before they exhibit their desired performance.

For the weekend racers in the audience, if you have ever used the Hawk Blue 9012 pads, then you know exactly what we're saying here. This material operates like a brake lathe (mega-abrasive mode) until it gets hot enough to stop on a dime (ultra-adherent mode). It's also why you shouldn't run Hawk Blue brake pads on the street—the brake temperatures will never get hot enough to get out of the abrasive mode and the rotors will pay the ultimate price.

A final interesting note on adherent friction: when race teams select adherent pads for their race cars, chances are that their rotors will actually be thicker than new when the time comes to replace them at the end of the season. Why? Because of the added thickness of the transfer layer material. The rotors may still need replacing due to cracking or other thermally-induced maladies, but rarely are race rotors replaced because they have worn too thin. They simply heat-cycle themselves to death.

### Brake v-v-i-b-b-r-r-a-a-t-t-i-i-o-o-n-n

So, now we can talk about brake vibration. As you read, you will find the underlying theme will revolve around preventing brake vibration, not curing it. But first, let's purge the phrase “warped rotors” from your vocabulary.

### Rotors Do Not Warp!

In nearly every single case, warped rotors are not physically warped at all. The common misconception is that the rotors get hot enough to distort and then, upon cooling, end up looking like a pretzel.

Contrary to popular belief, rotors simply do not warp in this fashion. The vibration that is felt in the steering wheel and floorboard is almost always caused by rotor thickness variation (TV), and the physical pulsing in the brake pedal is nearly always a direct result of the caliper piston extending and retracting as it tries to follow a rotor of varying surface thickness.

Take a second and re-read those last two paragraphs. They are that important!

TV is generally created in one of three ways. The least glamorous, yet most common form of TV is initiated when a truck is parked in the same place for an extended period of time. While it is sitting, a thin layer of corrosion (ferrous oxide, or rust) can form between the brake pad surface and the rotor. As you can probably imagine, sitting in humid or damp environments can greatly accelerate the corrosion.



**Pad printing is due to corrosion while parked. This is classic TV in the making, and pulsation is only a few miles away.**

When the truck is ultimately moved, there will be a localized high spot (an unintended transfer layer of corrosion) on the rotor which will wear at a different rate than the surrounding material. At first the condition is undetectable, but it will get worse over time as the rotor wears unevenly, creating high spots (thicker areas) and low spots (thinner areas).

For trucks which experience extreme brake use (Towing without a trailer brake comes to mind, not that you would ever do that, would you?) another common mode of TV is initiated by an uneven transfer layer of brake pad material on the rotor face. Without going into a doctoral dissertation on the subject, overheating the brake pad can generate an uneven transfer layer as the pad material breaks down and “splotches” (a highly technical term which one should not use without proper training and certification) on the rotor.

These uneven transfer layer deposits will wear at a different rate than the surrounding rotor material. On and on it goes until the high spots and low spots on the rotor face are severe enough to feel in the pedal. How much can be felt? In most cases, even less than 0.001” can be downright annoying.

The third most common source of TV begins with the overheating of the rotor itself. If a rotor gets really, really hot, it can develop evenly spaced, localized areas along its face which are much hotter than the surrounding rotor material. These hot spots will wear quicker than the cooler surrounding material, creating a thick and thin wear pattern on the rotor face. As the rotor cools, these thick and thin spots remain and will propagate with use until the TV is finally felt by the driver.

## How to Keep the Evil TV Monster at Bay

So now that we know what causes TV and the ensuing brake vibration, what can be done to prevent it in the first place? Don't worry if you don't have the answer already—we're professionals and can help you through this.

First, make absolutely sure to cool your brakes after extreme use (and NEVER stop while they are hot with your foot still on the brake pedal)! Anytime hot brakes are allowed to sit motionless, molecular bonds may continue to form between the brake pad and the existing transfer layer material (adherent friction in action). The result is nearly instantaneous TV generation.



**A rotor which has been exposed to an overheated brake pad.  
Note the friction material deposits on the face.**

Second, during extreme use, keep your brakes as cool as possible to reduce the opportunity for hot spots. A set of brake cooling ducts or an aftermarket exhaust brake goes a long way in this regard. Remember, cool brakes are happy brakes.

Third, if your truck is typically left outside for extended periods of time, it might be best to select a non-metallic brake pad. Non-metallic brake pads (also known as organic or ceramic brake pads) reduce the tendency to generate corrosion between the pad and the rotor. While they are not usually recommended for extreme-use applications, they don't rust as fast, and over time this may reduce the generation of TV.

Fourth, when installing your wheels and tires, be sure to tighten your wheel nuts in the manufacturer's recommended pattern and take several passes to reach maximum torque. In some cases, uneven tightening of the wheel nuts can physically distort the rotor enough that during normal driving thick and thin spots may develop on their own.

Finally, be sure to follow your manufacturer's recommended procedure for bed-in when installing new brake pads and/or rotors. These processes have been developed to reduce the opportunity for uneven brake pad material deposition on the rotor face when the pads and/or rotors are new.

## Bed-in Procedure? I'm Not Even Tired!

Whenever new brake pads and rotors are installed on your truck, you will need to properly develop a transfer layer. I bet nobody has ever told you that, have they?

The process of developing a transfer layer is typically referred to as brake pad bed-in (or more commonly known as break-in). In general, bed-in consists of heating a brake system to its adherent temperature to allow the formation of a transfer layer. The brake system is then allowed to cool without coming to rest, resulting in an even transfer layer deposition around the rotor circumference. This procedure is typically repeated two or three times in order to ensure that the entire rotor face is evenly covered with brake pad material.



**A typical rotor before bed-in. Note the clearly defined  
machining marks on the rotor face.**

Please note that the procedure that follows is completely generic and is only intended to introduce you to the theory of pad bed-in. Because this procedure is non-manufacturer specific, be sure to check with your brake pad supplier or vendor for any special considerations related to the bedding-in of your particular rotors and pads.

### James' Generic Bed-in Procedure

For a typical stock brake system, a series of 6 to 8 braking events from about 60mph down to about 10mph will typically get the brake components warm enough to be considered one bed-in cycle. Each of the 6 to 8 braking events should be made at moderate to high deceleration (about 75% of the deceleration required to lock up the brakes and/or engage ABS) and should be made one after the other without allowing the brakes to cool in between.

These are not extreme panic stops. Don't go overboard here.

Once the brakes have faded a bit and/or you smell friction material in the passenger compartment, the cycle is complete and you should allow the system to cool by driving at steady speeds without bringing the truck to a complete stop. After cooling, repeat the braking event procedure listed above one more time, cool down again, and you're typically good to go. In some situations a third cycle is beneficial, but two are usually sufficient.



**A typical rotor after bed-in. The soft gray haze on the rotor face is the transfer layer material.**

And now a word from the lawyers: Note that these speeds and maneuvers are neither recommended nor acceptable on all public roads. While you need to get heat into the system to achieve a proper bed-in, you also need to exercise common sense and take responsibility for your actions. Drive smart, please.

#### **But I Already Have a Brake Vibration . . .**

And what if brake vibration is already present in your truck? Well, that's a different story.

In select cases where brake vibration has just begun, it may be possible to remove any uneven transfer layer deposits from the rotor face by using a super-abrasive brake pad for a short while. This is a hit-and-miss strategy, and if uneven rotor wear has already started, then it's too late anyway. Remember, abrasive brake pads cannot make a rotor flat again—they can only smooth off uneven pad deposits.

Turning rotors can also alleviate the vibration situation, but may not be a viable long-term solution. If the rotor has been heated to the point that the chemistry of the rotor has changed (specifically, if localized areas of cementite have formed due to heat, yet another topic for the PhD's), then the vibration will come right back as the softer areas of the rotor face wear away more quickly. (Note that in some cases turning the rotors may not cure the vibration even for a short time, as these hard spots can deflect the brake lathe cutting tool making for an uneven cut on the rotor face.)

Unfortunately, the only known long-term solution to purging vibration is to replace the rotors themselves and properly bed-in the new parts, assuring an even transfer layer. It may sound like a brute-force approach, but desperate times call for desperate measures. Just be sure to learn from your mistakes to keep the evil TV monster from rearing its ugly head again.

What it all boils down to is that, in the war against brake vibrations, the best offense is a good defense. Until next time, I hope you are vibration free!

**James Walker, Jr.**  
**TDR Writer**

# Fuel and Lube Oil Additives

ISSUE 64

## MEDIA GIBBERISH/FUEL AND OIL ADDITIVES

by Robert Patton

Every now and then (some would say every day) there is e-mail, web site, or print correspondence; telephone or in-person conversation; or television or radio gibberish that makes me cringe.

Have you tried conversing with the television's one-way screen? Did you raise your voice? Did the misinformation make you crazy? Did you wonder how many others were misled?

How about an example close to home? A TDR member points me in the direction of the front page headline at Diesel this-and-that magazine's web site, "Automatic Transmission Fluid Fuel—Used ATF as Fuel? An Under-the-Radar Alternative Fuel Option."

I think to myself, "How darned irresponsible!"

So, I read the article. Bottom line, the writer's use of the "?" in the title and final paragraph warnings saved the text from being totally reckless. Nonetheless, the article told the story of a '02 Ford owner who was having success (I'd want a follow-up article in 20K miles to verify the word success), or should I say, the experience, of using ATF as fuel.

Ridiculous. Along the same lines are the man-on-the-street or new TDR member questions that I (and I'm sure you, too) get asked about fuel additives. "What do you think about Marvelous Mystery's fuel additive?" My short response, "Anything with a product title of 'Mystery' is just that, a mystery. And you want to put a mystery product into your fuel or lube oil? Not in my truck."

Often my answer is too blunt and time is subsequently spent soothing the bruised ego. To do so, I'll point back to TDR Issue 28's article by Kevin Cameron that tells the story in a more agreeable manner. Selected paragraphs from the text follow. You'll find the reread entertaining.

### Issue 28's Additive Discussion by Kevin Cameron

"The question of aftermarket oil additives keeps coming up (Steed, Prolong, STP, Microlon, world without end), and it always will. When a person has laid out big money for a shiny, wonderful new Turbo Diesel, that person intends to do more than just drive around in it. That person wants to have a relationship with that truck. The proper care is essential.

"In the old days, the relationship was easy. You changed your own oil every thousand miles, you ground your own valves, and you rotated your own tires. In fact there was more relationship between man and vehicle than most people wanted. That's why today's cars and trucks have become such turn key operations, with extended oil drain intervals and no tune-ups. Just get in and drive.

"This is the 21<sup>st</sup> century here, a time when people are concerned over things like dietary fat and bad cholesterol. Because we are what we eat, and we want to be good, we have to eat carefully. This applies by analogy to new trucks that have cost us \$32,000. Just as we are eating vitamin-C, DHEA, and no-flavor lean beef, so we are also tempted to pour expensive additives into the lubricating oil of our trucks, in hopes that performance will improve and that useful life will be extended.

"I read a wonderful line somewhere, which went like this: 'Vitamins were discovered in 1911. Before that time, people just ate food and died like flies.' Something like this idea seems to drive people today to use additives—ordinary pump diesel fuel and manufacturer-recommended oils can't be enough. Aftermarket additives are, therefore, the 'vitamins' we are tempted to give our vehicles. Never mind the fact that using 'Nosmo King' anti-smoke additive adds seven cents a gallon to the already high price of diesel. Never mind the fact that some highly-advertised 'super' oils cost more per quart than most of us pay for a case.

"The ads are wonderfully persuasive. One I saw recently featured regular guys strolling in a junkyard. They approach a rusty clunker, start the engine, and listen to its assortment of clatters—collapsed tappets, rod knocks, loose wristpins. 'Sounds pretty bad, Bob,' remarks one of the strollers. 'That's right, Bill,' returns another. 'We'll try a bottle of Noo-Life,' Bill confides to the viewer. They pour it into the engine and instantly the clattering goes away (or the technician at the audio mixer cuts the treble way down—it's hard to tell exactly which it is). 'Sounds pretty good now, Bill,' says the pourer, turning to the viewer and holding up the now empty Noo-Life bottle for our inspection of the label graphics. 'Why don't you try a bottle today?'

"In our minds, we know how it's done, but in our soft hearts, we're vulnerable, tempted to try a bottle. Yes, we know that unscrupulous used car dealers have, in the unregulated past, used sawdust to quiet timed-out transmissions, and we know that thick oil or a dose of motor honey (viscosity-index improver additive) will calm the high-frequency rattling of a worn-out engine. But, having laid out those thirty-two thousand ones end-to-end for that beautiful new truck (that's more than three miles of money), it just doesn't make sense to pass up products that might work, right? After all, they wouldn't let 'em say it on TV if it didn't work as advertised would they? Would they?"

Kevin talks about the \$32,000 truck. You can tell that Issue 28 is old. It was written in May of 2000. Yet, the desire to fortify your engine or fuel system with the latest vitamins does not diminish. Change the names of the vitamins Kevin mentioned in the first sentence to newer arrivals Slick 50, Z Max, Lucas, etc. and you get the picture.

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## Fuel Additives, Again

Fuel additive discussion seems to come and go at the various diesel truck web sites. As evidenced by Scott Dalglish's notes in his Issue 63 column (page 86), the topic is relevant with the writers too.

Yes, we all want to provide the best care for our trucks. The care is well-intentioned, but often unwarranted. So I'll repeat a definitive statement that holds credibility for me. The text comes from Scot's previous fuel additive discussion in Issue 63, page 86.

"Quoting from a previous TDR magazine, 'In several off-the-record discussions with service support staff the discussion has shifted to fuel conditioners as a maintenance practice for the '98.5 to '02 VP 44 fuel pump and the '03 to '07 HPCR injectors. The product recommendations: Cummins Diesel Injector Cleaner/Valvoline SynPower (3164982 – one quart), Racor Diesel Fuel Additive (ADT 1116 – pint), Stanadyne Junior (31417 – pint) Mopar (05191800AA – pint). Wynns makes the Mopar product.

"The message about fuel additives for the '07.5 and newer 6.7 liter engine is **not** the same. Because of the emission controls that are a part of the 6.7 liter engine, fuel additives are **not** to be used.

"No ifs, ands or buts. The answer is ULSD fuel only for the 6.7-liter engine.

*"That is the official response. As the 6.7-liter engine is approved for up to 5% biodiesel, I can only imagine that a ULSD-approved, fuel lubricity additive would be okay."*

## Fuel Additives – The Details

The preceding gives you the guidelines as set forth by Dodge and Cummins. To the cynic, the fact that there were but few products recommended for use comes as no surprise, "Did ya think those guys would recommend anything other than their own branded additives?"

Frankly speaking, no, and (cynic to cynic talking here) why would Dodge or Cummins recommend and test any other manufacturers' additives?

I see a stand-off here.

Additionally, inquiring minds want to know more and perhaps learn about their favorite brand. What is an editor to do?

Just as we did in our lengthy discussion on lube oils, I found a voice of authority.

TDR member Gerald Tobey works at a Bosch Authorized/ Association of Diesel Specialist (see ad, page 55) shop in Salem, Virginia, Blue Ridge Diesel ([www.blueridgediesel.com](http://www.blueridgediesel.com)). His credentials: a heavy equipment mechanic back in the 70's, a Pre-Tech Coordinator for Bosch, a trainer for fuel system repairs, builder of all major makes of fuel systems from the 70's on and an Association of Diesel Specialists Certified Diesel Injection Technician.

## GTobey's Response to Additives

The following are Gerald's thoughts on fuel additives for diesel engines.

In late December there was much discussion at the TDR website about fuel additives. The editor saw my shoot-from-the-hip response and asked me to take aim at helping the larger magazine audience understand their fuel injection system. The web discussion started with a question about 2-stroke and ATF fluid. Watch out for stray bullets...

I was just wondering, why would you want to put something in your fuel system that wasn't designed to be there? Two-stroke oil was not designed for diesels, and where in *any* application is ATF supposed to be combustible? (And if it combusts, I don't want it in my transmission!). Mineral spirits? (Okay, who poured that gallon of paint in the fuel tank?) And, as for used engine oil, after seeing the oil sample analyses from many, many diesel engines used in over-the-road, industrial, construction, and agricultural engines over the years, I wouldn't put *any* used engine oil in a neighbor's lawnmower.

Back in the late 70's and early 80's, Racor used to sell a filtration cart to "filter and blend" used diesel engine oil into diesel fuel, up to a maximum of 5% by volume. Even then, they recommended that the used oil be tested for presence of antifreeze, and not to blend that oil into the fuel if it was contaminated. But as injection systems developed higher pressures, tighter tolerances, and hydrocarbon emissions were reduced, that practice was discontinued. Most manufacturers also rescinded that practice. By the time you pay to have for an oil analysis to see what the percentages of contamination are in the lube oil (that you really don't want going through your injectors), you could buy the proper diesel fuel additive and use the right thing.

The Stanadyne Performance Formula additive was explicitly designed for your diesel fuel system as are some additives manufactured by other companies. For example, during Operation Desert Storm, our military was experiencing pump and injector failures on the GM HMMWV ("humvee") because they were using JP8 jet fuel. They requested that Stanadyne, a manufacturer of diesel fuel injection equipment, invent a product to allow them to use JP8 in their diesel engines. I guess the old adage "necessity is the mother of invention" is true. Stanadyne's "Lubricity Formula" was invented and it has performed well to this day. If it will add the proper lubrication to JP8 to allow it to be used in a diesel injection system, then it will work wonders for ULSD! We have also found it to work wonders for local airport vehicles where they are allowed to have only jet fuel on the tarmac, and they successfully use jet fuel in those diesel vehicles with the Lubricity Formula.

Regarding the desire to put something in the fuel and protect your investment, here is where my opinion differs. What I wonder about is the methodology that some folks use to choose a specific item to put into their fuel systems. Sometimes, it seems a person has given it proper thought and investigation, and other times only their feelings or pure non-scientific experimentation, and they dump in a dose of "whatever"!

Some of the worst failures we found were from the vehicles that were hauled in on the back of a flatbed truck. They ranged from single cylinder air-cooled diesel engines, to VW Jetta diesels, to Ford E-450 buses. I've seen home-brews that were made with absolutely zero cetane; some liquids that the labs could not identify as fuels; some "fuel imposters" from the internet equipped makers of a bio-fuel; something liquid with a paint like smell that would cloud up at about 45°; methanol flavored diesel/veggie oil mixes; to the commercially produced bio-fuels (although we never saw the ASTM approvals for them). All of these engines experienced some sort of failure ranging from plugged injection nozzles, to failed fuel injection pumps, to leaking hoses, to plugged filters, to stuck rings, to even exploded pistons.

The stories even hit close to home. A neighbor provided the KFC waste vegetable oil (WVO) to a Jetta owner who strained it through a cheesecloth filter and then straight into his tank. (He must've had to strain it to remove the popcorn chicken chunks!) This new car had only a few thousand miles on it, but expired shortly after the WVO was introduced. He lost all of his fuel savings and more in having to pay for the major repairs to the engine and fuel system!

Before we had ASTM standards for biodiesel (Issue 62, page 48, June 2008) several of our local municipalities mandated the use of "green" fuels in their vehicles and equipment, as is trendy in all areas now, so that their administrators can claim that their fiefdom is more eco-friendly than another. Hence, along came the introduction of commercially available bio-diesel into the fuel being used by that municipality. The municipality was using a 2% blend, and most all of these vehicles are sporting the green bumper sticker touting that they are eco-friendly, implying they are saving the planet with the use of bio fuels. After just one quarter of the year, one maintenance department found that they had changed over 400 fuel filters in their diesel equipment, four times their normal usage. To add further insult to injury, they had to purchase 3 new gasoline powered service trucks and trailers to haul the broken down equipment back to the shop. The local taxpayers have to bear the brunt of the increased costs.

Now, I'm not saying that biodiesel fuel can't be used. There is comfort in the fact that there are now ASTM specifications and testing for 5% bio-blends (Issue 62, page 48). Just be careful.

Our shop has experienced first-hand some of the problems with ULSD and we have discussed these issues with some of the tanker drivers in our area. I have also read the posts from other tanker drivers in the forums on the TDR website. They have told us about difficulties in providing the correct amount of lubricity when the fuel is loaded onto the trucks. We understand that the pipeline companies are forbidden to push #2 diesel through the lines if the lubrication has been added at the refinery because the FAA will not allow jet fuel to be contaminated with the lubricity additive residuals from the pipeline. The responsibility of adding the correct lubrication then shifts to the tank farms or to the truckers when they load the fuel into the tanker truck.

Early on in the implementation of the ULSD fuel we had an instance involving two land-adjointing farmers who purchased identical tractors from a dealership on a "two for" deal. They decided to go together to get a load of diesel fuel for their storage tanks to

save money by buying in quantity. Oddly enough, within 10 days, we had two failed fuel pumps in our shop, and the tractor dealer was asking for warranty consideration. The hour meters on both tractors indicated less than 100 hours of running time. Careful inspection revealed that both failures occurred due to the lack of lubrication in the fuel, which is not a failure or defect in workmanship or materials. Both pumps exhibited the same failure. The tractor dealer then asked for warranty from his tractor manufacturer, who stated it was the fuel injection equipment manufacturer's problem. The customers just wanted their tractors back and any repairs necessary to be covered under warranty. The fuel distributor stated that they had plenty of lubrication added to their diesel fuel and would not accept any responsibility for the problem. The finger pointing and tempers really get to flaring when this kind of event occurs, putting all parties involved into a difficult situation.



**This picture shows the supply pump ring from the internal transfer pump of one of the injection pumps. It visibly shows the damage to the transfer pump liner from lack of lubrication. The transfer pump vanes are in the center of the ring and exhibited major scoring on their sides and ends, and material from the ends of the vanes can be seen transferred to the liner surface.**

This sort of failure has abated somewhat since the initial implementation of ULSD, although we do still see it from time to time.

Years ago, the pressures in diesel injection systems were somewhere near 17,000 psi ('98.5-'02 engines). Today, with the advent of common rail fuel injection and piezoelectric fuel injectors, injection pressures are upwards of 27-29,000 psi. These piezoelectric fuel injectors can meter fuel through their fine nozzle holes with extreme precision. Because of the design, they can open and close the orifice four times faster than a solenoid valve actuated injector. This is fast enough to allow up to five discrete needle valve openings over the course of a single injection event. With these types of multiple injection events, the pressure rise in the cylinder is far more gradual, and the result is reduced emissions and noise at every engine speed and load.

Because fuel injection systems are getting more and more precise, proper fuel quality requirements become imperative. Filtration requirements have become more stringent, and Cummins recommends that the 7-micron filter replace the older type cartridges, especially for the common rail engines [use Fleetguard FS19856 for '03 to '07 5.9-liter engines; use the new FS<sup>2</sup> filter (see page 50) for the '07.5 - '09 6.7-liter engine].

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Now, here is a story that can be labeled absurd. When 2-micron fuel filter assemblies became available back in the '80s, we would install some on engines that were experiencing pump and injector failures from dirty fuel. Wouldn't you know, the very next complaint was that the fuel filters were "stopping up" too fast! They wanted to go back to the 10 or even 30 micron ratings so they could have longer filter life! Of course this was at the expense of their pumps and injectors, creating the problem that they were trying to avoid. Yes, absurd.

If you wish to fund the experimentation of using products in applications for which they were not intended, and you have the wherewithal to do it, by all means, go for it! But, do it with industry recognized scientific methodology. Have a control group, experiment under controlled conditions and document your findings so that you don't spend that good money for bad. Performing tests in any other manner would be no different than doing the same thing over and over and over, yet expecting different results each time. (Editor's note: Gerald, that's the definition of insanity!) Finally, just because you don't have an instant failure does not necessarily mean you have discovered the cure for a problem.

**Gerald Tobey**  
**Blue Ridge Diesel, Salem, Virginia**

### **Conclusion**

While the jury may be out for deliberation, the judge (that's me!) has reached a decision.

This is not to say that my opinion has not been influenced. Several years ago we posted an article that showed the benefits of this-and-that fuel additive. But you'll not see those types of analysis using up printed space in the TDR. Should you wish, there are numerous fuel system and lubricity additive studies on the web. Do a search and you will see what I mean. Be careful as you try to determine if the study is biased.

For me, I'll follow the advice of Dodge, Cummins, Kevin Cameron and Gerald Tobey of Blue Ridge Diesel.

**Robert Patton**  
**TDR Staff**

# Death Wobble

ISSUE 74

## STEERING WOES

### Introduction

by Robert Patton

In a staff meeting a Geno's Garage employee shared with me the latest find from the newsstand. The headline from Diesel-This-And-That was "Cure for the Dodge Death Wobble."

Wanting to learn about the one-size-fits-all "cure," he purchased the magazine, hoping to read about the definitive answer.

If there is a single part to cure the steering problem, all Turbo Diesel owners would like to know about it. You'll find that I'm not so bold as to suggest the one-size-fits-all approach, especially considering that we have four generations of trucks to consider.

As I read the article in Diesel-This-And-That, I looked closely for the author to give himself an "out." You know, using words like possibly; maybe; double-check your (fill in the blank); also consider (fill-in-the-blank). If the words were used, I missed them. Their suggested cure was the combination of a steering stabilizer and a replacement track bar, quite an expensive repair.

Again, I'm not so bold to suggest a single answer. I would rather share with you the experiences from vendors, TDR writers and TDR members. So in this article "Steering Woes" you'll find a compilation of correspondence that will get you started in the direction of correcting the problem rather than replacing parts that may or may not help. An outline of this article looks like this:

- "Overview of Suspension Components,"  
by TDR Writer Andy Redmond
- "A Comment on First Generation Trucks,"  
by TDR Writer Andy Redmond
- "Is it a simple "Rebuild of the Trackbar?"  
by Luke's Link employee Michael Engle
- "Comments on '94-'02 Death Wobble,"  
by TDR Writer Andy Redmond
- "Steering Woes on a '94-'02 Second Generation Truck,"  
by TDR member Brent Boxall
- "Preferred Alignment Specifications Update"  
by TDR Writer Andy Redmond

Finally, I am fortunate in that I have not had any steering problems with any of the five Turbo Diesel trucks that I have owned. You can chalk this up to the fact that all of my concrete-cowboy needs are met with two-wheel drive trucks. Without the need to tinker with the steering components, I am not qualified to offer advice. However, TDR writer Andy Redmond works on these trucks day-in and day-out. So, throughout the article you'll find "Andy Redmond responds:" as he adds commentary to the other writer's material and at the end of this compilation of data, he updates his Issue 53 article with new alignment specification that includes '03-'09 Third Generation trucks. Let's get started with Andy's article "An Overview of Suspension components," followed by his "Comments on First Generation Trucks."

## AN OVERVIEW OF SUSPENSION COMPONENTS

by Andy Redmond

The focus of this article on "Steering Woes" is primarily written for those '94-'02 Second Generation owners. However, I thought I would put a basic table together to show the type of suspension and known problems to cover all years of Turbo Diesel with the 4x4 drivetrain.

Owners should note that in 2003 the track bar was redesigned with the introduction of the American Axle for the Third Generation trucks. With the exception of the lesser quality ball joints and hub bearing assemblies, the front suspension on these '03 and newer, later generation trucks is substantially more robust and durable.

| YEAR      | FRONT SUSPENSION TYPE                                                                                                                                                                                                                                                                                                 | KNOWN PROBLEMS                                                                                                                                                                                                                                                                                 |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1989-1993 | Leaf sprung-solid axle—Dana 60                                                                                                                                                                                                                                                                                        | Steering shaft rag joint. King pin wear and perhaps worn bushings in leaf spring eyelets                                                                                                                                                                                                       |
| 1994-1999 | Link coil (upper and lower trailing links with coil-sprung solid front axle—Dana 60). This truck uses a track bar to align the axle between the frame rails.                                                                                                                                                          | Track bar wears out quickly (due to ball stud end). Small eccentric adjusters on lower trailing arms allow for insufficient positive caster adjustment. Steering gear that wears over time.                                                                                                    |
| 2000-2002 | Link coil (upper and lower trailing links with coil sprung solid front axle—Dana 60). This truck uses a track bar to align the axle between the frame rails. There was a design improvement with the dual piston brake calipers, non captive rotors, different spindles, ball joints and larger alignment eccentrics. | Same problems as earlier Second Generation trucks, but now the ability to achieve preferred caster adjustment, due to design changes in the lower trailing arms (larger caster eccentrics). Steering gear that wears over time.                                                                |
| 2003-2009 | Link coil suspension (American Axle)                                                                                                                                                                                                                                                                                  | Lesser quality ball joints and hub bearings. Much improved track bar design and attachment point (track bar has two eyes, versus the poorly designed earlier style eyelet/ball stud design). A switch to a Delphi steering gear from the Saginaw part. It too suffers some reliability issues. |
| 2010-2011 | Link coil design similar to 2003-2009 models                                                                                                                                                                                                                                                                          | Many subtle changes including larger sway bar links, redesigned track bar, larger steering gear/steering linkages. This steering gear shows promise of being over engineered and very robust!                                                                                                  |

I know, I know, you want to read about *the answer* to your steering woes, specifically those woes that pertain to the '94-'02 Second Generation trucks. We will get to the answer in due time. Do you dare skip ahead to my "Comments on the '94-'02 Death Wobble" or is it as simple as a "Rebuild of the Trackbar." Read on!

#### A COMMENT ON FIRST GENERATION TRUCKS

by Andy Redmond

As expected, the First Generation truck handled pretty well, although they didn't ride too nicely. The handling and long wearing front end parts are classic old school—a solid front axle, with leaf spring suspension, tapered roller wheel bearings and manual locking axle hubs. The steering shaft's "rag joint" is the most common steering issue. Even if the king pin (steering knuckle pivot points), and various steering end links are worn, the leaf springs center the axle (between the frame rails), resulting in a truck that usually drives fairly straight.

#### REBUILD OF THE TRACKBAR?

by Michael Engle/Luke's Link

Anyone who has experienced steering problems while driving a Dodge pickup truck knows all too well the symptoms: wandering or drifting and/or a shimmy, or even a violent shake when hitting a bump, known as the "death wobble." When trying to identify the specific problem, most people look to vehicle alignment, worn ball joints, steering boxes, or even tires. However, don't overlook the real problem: the ends of the track bar.

For the novice that is new to four-wheel drive, the track bar is the bar that sits under your differential and runs from the axle to the frame. This bar acts as a stabilizer to keep the truck tracking straight as it travels down the road. From '94 to '02 (Second Generation trucks) the track bar had a bushing on one end and a ball joint on the other end. Many people mistakenly replace the entire track bar when the true cause of the problem is simply the ball stud on the driver side end of the track bar. Internally Dodge put a two-coiled metal spring to hold pressure on the ball stud. Once this spring (which is not strong enough in the first place), flattens out, the bar sits on the ball stud and moves up and down. Below is a picture of the spring that wears out.

Wandering or drifting occurs while driving because when the steering wheel is moved, the track bar pulls the axle, and that "play" in the bar lets the axle keep moving. This causes the driver to pull the steering the other way and you end up constantly steering the truck.

The death wobble occurs when shock or vibration is sent from the axle to the track bar, causing the bar to shake because of the play. The shake is then sent to the frame of the truck which makes the truck shake. Generally you must slow the truck to allow it to regain its "composure."

So if you are facing either of these problems, what do you do? Some might think going with a thicker track bar will solve this problem. A thicker track bar (with the same "sloppy" ball stud) will not last any longer than the stock bar. Likewise, regardless of a lifetime warranty that is offered by some manufacturers, it is likely you will be changing track bars every 6 to 12 months.

So what is the solution? Luke's Link of Colorado offers a permanent solution to Dodge pickup tracking problems. At Luke's Link our line (technically speaking, a ball stud socket collar) was designed to rebuild and convert track bars to a fully adjustable end. With this

kit, you remove the ball stud and internal parts and slide a cap or C-clamp over the end. You then install the new modified internal parts with the new modified spring being the main component. Then a large plug screws into the cap to tighten everything down. With this setup, the ball joint will never wear out. If it does, you can adjust it by unscrewing the plug and putting a spacer under the plug to shim the spring down. This only takes a few minutes to adjust. This allows the track bar assembly to last for the life of the truck.



**The Luke's Link replacement ball stud parts.**

Luke's Link has a simple check and test to determine if your track bar ball stud is bad.

- You need two people to complete the inspection, and at least one person should have some fairly good strength. Make sure your vehicle is parked on a solid surface with tires pointed straight forward. *Do not* jack the truck off the ground.
- Have the stronger person sit in the driver's seat and unlock the steering wheel. *Do not* start the engine! The other person should be under the vehicle with a flashlight.
- The person in the driver's seat should move the steering wheel back and forth fairly hard. Under the vehicle you should examine the ball stud joint to see if there is any movement up or down. Make sure you are looking at the track bar as well as the tie rod ends. The main objective is to use the weight of the truck against the axle. That is why it is important to leave the truck completely on the ground. If there is movement, your ball stud joint is likely in need of replacement. (Please note that the tie rod ends will swivel and that is normal. The track bar, however, should not move at all.) The entire replacement part kit for this repair is \$69.

### About Luke's Link

Luke's Link has sold tens of thousands of repair kits in the United States and internationally, and is recognized as a leader in specialty auto products. We've been in business for over 25 years. We've been prominently featured at many automotive web sites and in publications including Peterson's 4x4 Magazine. Owner/Operator/Inventor Johnnie Laucus has owned a front-end shop for over 30 years. Laucus and his engineer continue to expand and improve their product line. In addition to this kit working on the Dodge track

bar, it will also work on the tie rod ends from '94-'06 as well as Jeep track bars and most Ford tie rod ends up to '98. Luke's Link also has developed a kit for the Dodge '03-'07 track bar bushings. The bushing kit includes two poly bushings, and new better fitting bolts for the ends. This set is \$36 and eliminates the need to replace the entire \$350 track bar.

Please don't confuse Luke's Link kits with a cheap or temporary fix. Luke's Link offers low cost solutions because it permanently solves the problems, with no need to purchase expensive or unnecessary parts. See Luke's Link on the web at [www.lukeslink.com](http://www.lukeslink.com) or contact us at 1-800-962-4090.

### "COMMENTS ON THE '94-'02 DEATH WOBBLE"

by Andy Redmond

Luke's Link is a great company with a great product. However, I've experienced only marginal success unless the repair kit was installed on a lightly worn track bar. The kit often was not able to tighten the worn parts enough, allowing continued death wobble. Unless Luke's Link has been updated, their directions state it will not work on the slightly more heavy duty Moog DS1413 track bar.

For the Death Wobble problem on a Second Generation truck, I wrote an article in Issue 46 (November 2004) that covered the installation of a truck bar relocation bracket and a new Mopar '03-'08 track bar. Since the editor sent this article to me for my review, I went back seven years to Issue 46 to see if my opinion had changed. It has not. As I mentioned, the repair is more involved than the simple rebuild of the track bar with a Luke's Link. The parts used back then were a track bar relocation bracket from Solid Steel Industries ([www.solidsteel.biz](http://www.solidsteel.biz), part number DSS0019402-4, \$209) Mopar '03-'08 track bar (part number 52106795AC, at about \$250). I still use these parts. Since 2004 other companies have introduced different versions of this kit; specifically, the folks at BD Power offer a bracket and track bar kit (BD part number 1032011, \$480). My experience with the BD kit is that it is more difficult to install. The Issue 46 article (pages 154-156) has the details of the SSI bracket with the Mopar track bar.



**The Issue 46 article (pages 154-156) has the details of the SSI bracket with the Mopar track bar.**

## STEERING WOES ON A SECOND GENERATION 4X4

by Brent Boxall

The problem with steering issues is that they come along slowly. Mine began at about 120,000 miles with a mechanical “clunky” feeling in the steering wheel, and with 141,000 miles on the clock, my 2001 Ram 2500 Quad cab 4x4 had developed a tendency to move around in the lane without driver input. I never experienced the “death wobble” many speak of, but I’m sure I was a DUI suspect from time to time, especially when towing. This wandering steering issue made the truck a handful to drive so I decided to fix it. Below is a description of what I did to fix my truck, beginning at about 120,000 miles and completing the repair at about 141,000 miles. This article is not intended as a how to guide, but rather is a list of the steps I took when repairing my truck. As always, your mileage may vary.

I fixed my steering in three phases: one being from the steering column to the steering box; the next from the steering box to the wheels; and finally phase three, the tie rod ends and ball joints.

### Phase One: Steering Column to Steering Box – Chasing the Mechanical “Clunk”

After searching the truck’s steering system for loose motion, I decided that the steering shaft in the bottom of the column felt slightly loose. The best way to check this is to stand next to the left front wheel and reach down below the master cylinder and grab the shaft where it comes out of the column tube. Pull the shaft up and down and feel for mechanical play or loose motion in the column bearing. Remember that a little bit of motion, like 0.002-0.003” can feel like a lot in the steering wheel.

To investigate further I removed my original steering shaft that connects the column shaft to the steering gear box. This shaft felt good in my hands when checking for rotational slop, until I realized that I had it telescoped to a different spot in its extension range than where it rode when in the truck. Upon more careful inspection I realized that at the exact point in its extension range where it was installed in the truck it had a slight amount of rotational slop, less than 1 degree, but still noticeable.

To fix one of these issues I decided to replace the bearing in the bottom of the steering column with the bushing offered by <http://rocksolidramtrucksteering.com>. The instructions supplied with the kit were very straightforward and it appears to be somewhat easier to do on my truck given it is a manual rather than the automatic trucks with the column gear selector.

One note worth mentioning here is that any time you uncouple the steering system, the steering wheel is free to turn inside the cab. This must not be allowed to happen as it may bring about the destruction of the “clock spring” inside the column. The clock spring is actually a thin ribbon cable type electrical connection between the portion of the column that rotates and the part that doesn’t rotate. The catch here is that the cable or clock spring is a fixed length so if you connect the steering back up in a different orientation than it currently is, you may run out of cable when turning left or right. The best way to avoid this is to put the truck’s front wheels straight ahead prior to disassembly. Then take a cargo strap and attach it to one of the driver’s seat floor supports, thread it through the steering wheel and connect to the other seat support as shown below:



This technique makes the steering stay put while you work which avoids clock spring damage.

**Andy Redmond adds to Brent’s story: The bushing offered by “[rocksolidramtrucksteering.com](http://rocksolidramtrucksteering.com)” is a worthy modification, more for steering column wear and noise more so than handling concerns. Dodge offers a toe plate bushing for later steering columns in the Second Generation trucks, which is used to solve the problems of column wear and noise (clunking).**

To replace the steering shaft I chose the Borgeson steering shaft, part number 950. The installation instructions for the Borgeson are straightforward and easy. I highly recommend test fitting the steering shaft and then using Loctite for all set screws and jam nuts. Again, follow Borgeson’s instructions, your steering system is IMPORTANT!

While I had the steering shaft out of the truck I removed the steering gearbox to check the play in it. The easiest way to get the steering box out is to remove the hydraulic lines and remove the tie rod end on the Pitman arm. The Pitman arm retaining nut came off easily but the arm seemed not to want to move. I chose not to remove my Pitman arm since it was stuck hard even after soaking with penetrating oil. I put the steering box on my bench and tried rotating the input shaft very slightly to see if I had Pitman arm movement. Using a dial indicator I determined that my steering box had very near zero loose motion in it, so the steering gear box went back in the truck.

**Andy Redmond adds to Brent’s story: To adjust the steering box for wear, I use the procedure outlined in Dodge technical service bulletin (TSB) 19-10-97. Where do you find this oldie (written in 1997)? The TDR’s web site has a summary of the bulletin and a web search on “TSB 19-10-97” will uncover the entire bulletin.**

Every steering gear I’ve tightened has resulted in better steering manners (less steering wheel motion before the truck starts to change directions) after tightening the preload. Please realize that this preload adjustment does not address any side play in the sector shaft that is connected to the Pitman arm.

And, although Brent didn't remove his Pitman arm, I've found that before attempting to remove the arm it helps to wire brush everything, followed by a dousing of brake cleaner, chased by some penetrating oil. If needed, try some heat from a small torch. Sometimes a pneumatic impact wrench on the Pitman arm puller is necessary to pull a stubborn Pitman arm. I've even broken high quality Pitman arm pullers, "abusing" them in such a fashion. However, I've always been able to remove the Pitman arm without Pitman arm or steering gear damage, all with the steering gear on the truck!

One problem became readily apparent when I removed the power steering hydraulic hoses. My power steering fluid smelled burned and was unnaturally dark in color. I then decided to take the power steering pump off and check the condition of the pump. This observation fit with the extremely high temperature of the hose fittings near the hydraulic brake assist unit I have observed over the life of the truck. I decided to do something about high temperature of the power steering fluid. So I found an automatic transmission fluid cooler that would fit on the driver's side of the air conditioning condenser in front of the intercooler. I designed a bracket and mounted the cooler in line in the return hose from the steering gear box back to the power steering pump reservoir.



An automatic transmission fluid cooler in its new job as a power steering fluid cooler.

This fluid cooler plumbed into the return line worked like a charm to keep the power steering fluid cool. Even on a 100° day, after driving in traffic, you can put your hand on the return line going from the cooler to the pump reservoir and it is warm/hot to the touch, a major improvement over the "roast your finger" stock system.

Problems arise! This new system worked great but the stock pump either did not have the pressure or enough flow to operate the system if I was braking while turning during slow speed maneuvers and/or when the engine's speed was near idle. This can be attributed to the additional return line back pressure created by cooler and the additional 8-10' of hose required to get out to and from the cooler. One way to tell if your power steering pump is having trouble keeping up flow-wise, is to turn the steering wheel very abruptly when the truck is moving very slowly. You will feel the power assist "catch-up" a fraction of a second later. This is a major

indication that your pump isn't providing enough flow. The way to tell if your power steering pump isn't making enough pressure is during stopping and turning. If the pump pressure is low the power brake assist will be weak requiring more brake pedal pressure to stop and steering effort is increased especially noticeable during low speed maneuvers.

West Texas Offroad ([www.westtexasoffroad.com](http://www.westtexasoffroad.com)) has a good description of the Saginaw pump pressure regulator and how to modify it, which I did, but still couldn't get enough performance from the stock pump. If I adjusted for pressure, I didn't have enough flow and likewise if I set up the pump for adequate flow I lost too much brake power assist and slow speed power steering assist.

Save a link to the "Tech" section of the West Texas Offroad website. The technique of removing a spacer washer to increase pressure is outlined in the next paragraph.

While searching for power steering pumps, I found Performance Steering Components at [www.pscmotorsports.com](http://www.pscmotorsports.com). After talking with them on the phone I learned that our trucks come stock with a Saginaw 1300 Series pump and PSC offers 1300 series pumps as well as a 1400 Series high performance pump. The 1400 requires a fluid cooler, which I had just installed, so I ordered their part number SP1490. After installing the pump and some Royal Purple Max EZ Synthetic power steering fluid, I figured I was set. The pump did great on flow, but required some effort to turn the front wheels in a parking lot and also a heavy foot to stop the truck. Now the information from West Texas Offroad comes in handy on the pump pressure regulator. Take the high pressure hose off the pump and unscrew the pressure regulator per the West Texas instructions. You will notice that the PSC SP1490 comes with two pressure regulation washers on the regulator shaft. Remove one of them and reassemble. After putting fluid back in the reservoir and purging the air out of the system, it was picture-perfect. The steering was one finger, even while stopped, and all the flow you could ask for was there. I tried stopping while turning, which uses both the hydraulic power brake assist and the steering. All worked perfectly. Brake assist during a simulated panic stop was also excellent.

**Andy Redmond adds to Brent's story: For 85% of TDR members considering such a modification, they would be smart to order the cooler/better Saginaw 1400 series pump from PSC as a kit.**

**Shimming the pressure regulator can cause exactly what Brent explains; plus, when shimming the OEM pump, I have seen the pump let go internally, leaving you with no power steering (and no power brakes—'97 to '02 hydro-boost equipped trucks), often within a few minutes of the shimming process. This is a huge safety concern. Shimming a pump is an exact science, particularly impractical without pressure gauges and a flow meter.**

The Rock Solid column bushing and Borgeson steering shaft fixed the clunky mechanical slop in the steering wheel and the roasted power steering fluid problem was taken care of with the fluid cooler and high performance pump. These changes made the truck steer better than stock!

Okay, the clunky feel to the steering was gone, but the truck still wandered around in the lane, most noticeably at freeway speeds. My plan to change only so much of the system before proceeding with further changes was tested by commuting in the truck every day for a couple of months. Phase One was complete. Time to start Phase Two.

### **Phase Two: Steering Box to Wheels – Chasing the Wandering Ram.**

One of my initial tests prior to beginning any steering work on the truck was to jack up one front tire at a time and try to rock the elevated tire in and out, top to bottom, and left to right, thinking that I could isolate loose motion to a specific ball joint or tie rod end. This test yielded no loose motion no matter how much I pushed and pulled on each tire. This made me wonder if the steering was really bad or if losing my driving skill was part of the aging process! I somehow convinced myself that the track bar must be the problem, and the truck was just too heavy for me to physically detect slop in the track bar.

**Andy Redmond adds to Brent's story: Ahhh...training and experience helps when you are looking for component wear. I and other TDR writers have provided good instructions over the years on identifying loose and worn chassis parts. Our techniques are similar to Michael Engle's method (the preceding Luke's Link narrative). The basic test: an assistant sawing on the steering wheel (wheels on the ground) to test track bar and steering linkages. This, followed by a slightly raised tire, then utilizing a long pry bar (while an assistant watches) to check the ball joints and hub bearings. These methods of testing will allow you to see any worn components.**

I ordered a Moog DS1413 track bar from Rock Auto and installed it. Installing the track bar is a fairly straightforward operation: just remove the bolt from the axle connection on the passenger side and remove the nut from the ball stud accessible from the driver's side fender well. Removing the driver's side wheel is a major help. To get the stud to back out of the tapered hole in the frame use some penetrating oil and a small sledge hammer to bump it out.

**Andy Redmond adds to Brent's story: Ahhh...training and experience with too many sledge hammers helps when you are trying to remove tapered ball studs.**

**Before you resort to the hammer method, try a pickle fork, a modified Pitman arm puller or a Miller/SPX tool C3894-A to break the tapered ball stud free.**

Just in case you missed it from my earlier discussion in "Comments on the '94-'02 Death Wobble," my cure-all is a combination of two parts: a track bar relocation bracket and a '03-'08 Mopar track bar. Installed on a customer's '95 Turbo Diesel 2500, his truck has over 150K miles of trouble-free operation. These parts should have been factory installed!

Although my kit came from Solid Steel Industries, I have also had occasion to install the kit from BD Power. The BD variant is more difficult to install as it also requires tedious alignment and, in some cases, later drilling holes in the cross member.

I chose Moog parts for all my front suspension replacements. It is easy to see why the Moog components are better, below is the new Moog track bar lying next to the stock bar.



This track bar replacement settled the truck down quite a bit and gave it some fairly decent road manners. I drove the truck for several months with it at this stage and decided that while it was tolerable, it still lacked the control and stability it had when new.

Since I found the steering box to be good in the Phase One inspection, I decided to look at the steering output shaft and tie rod end. I had an assistant get in the truck while it was sitting in the driveway, engine not running. I had him rock the steering wheel back and forth very slightly while I put my hands on all the joints including the steering box output shaft. It appeared that the steering shaft bearings/bushings inside the steering gearbox were good. I decided that I didn't like the steering box output shaft sticking out without any support on the "free end" and realized this could be a durability problem, so I decided to order and install a BD steering box stabilizer from Geno's Garage. The BD stabilizer is basically a steering box output shaft extension and support bearing. You remove the Pitman arm nut and then add the BD shaft extender. Next you remove the four bolts holding your front sway bar to the truck and install the BD stabilizer under the sway bar brackets, using the sway bar bolt locations and longer bolts supplied with the kit. A self-aligning flange bearing is then added to the BD stabilizer to support the newly extended output shaft. Again, follow BD's installation instructions.

The picture below shows the BD steering box stabilizer installation after two years of use.

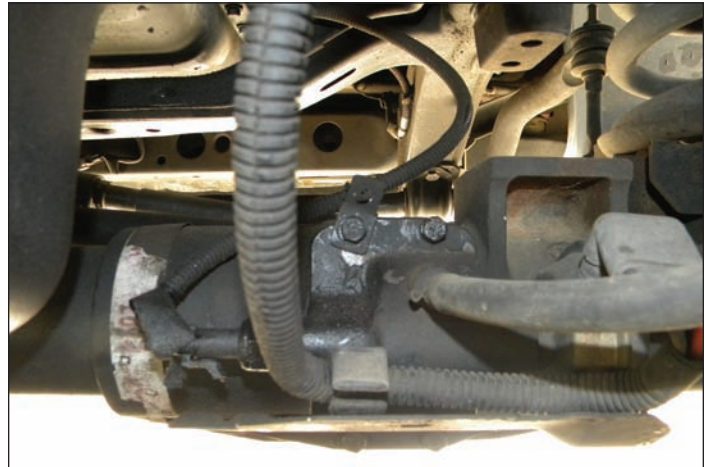


The BD steering box stabilizer enhances the truck's steering system by giving the steering shaft support out past the point of load application which reduces stress on the steering box's output shaft bearings. It also stiffens the frame rail near the steering box mounting location, reducing side-to-side flexation.

### Phase Three: Ball Joints and Tie Rod Ends

The ball joints and tie rod ends are the only tasks left! Many will advise putting the truck in four-wheel drive prior to removing the front axle half shafts. Engaging 4WD puts the spline engagement collar (central axle disconnect – CAD) inside the axle housing half on the intermediate shaft and half on the passenger side half shaft. This allows you to remove the passenger side half shaft without the collar falling down in the housing. If you leave the truck in 2WD as I did and remove the passenger side half shaft, the spline engagement collar will fall down in the engagement housing. This is not a major issue at all since you can disconnect the 4WD sensor and remove the four 1/4-20 bolts holding the spline engagement actuator/housing cover. Once removed simply put the collar on the intermediate shaft while reinstalling the passenger side half shaft. Then position the collar on the spline so that the actuator fork engages the collar and you can bolt up the actuator/housing cover. I recommend removing the spline engagement housing cover anyway to wipe the old differential lube and crud out of the sump.

Spline engagement housing on back side of front axle.



Before you put the truck up on the four jack stands, remove the hub caps and take the half shaft hub nuts off. This requires first removing the cotter pins and then a 1 11/16" socket. Penetrating oil and patience are important components for this phase of the project. In my experience the best penetrating oil you can get is mixture of 50% acetone and 50% automatic transmission fluid. One word of caution is that the penetrating oil isn't friendly to the clear coat on your aluminum wheels, so caution with runoff is necessary. However, repeated application of penetrating oil over a week's time prior to disassembly will make the job go much easier, especially with the bearing hubs.



My old Chicago Pneumatic 1/2" impact wrench having a go with a 3/4" socket adapter and 1 11/16" socket. Both nuts are standard clockwise tighten so remember patience and penetrating oil. My impact wrench took about 20 seconds per side and the nuts were off.

## Safety Reminder

For working on the front suspension the truck must be up in the air so that you have clearance to work. For pressing ball joints out of the axle you will need quite a bit of ground clearance for the 'C' frame press.

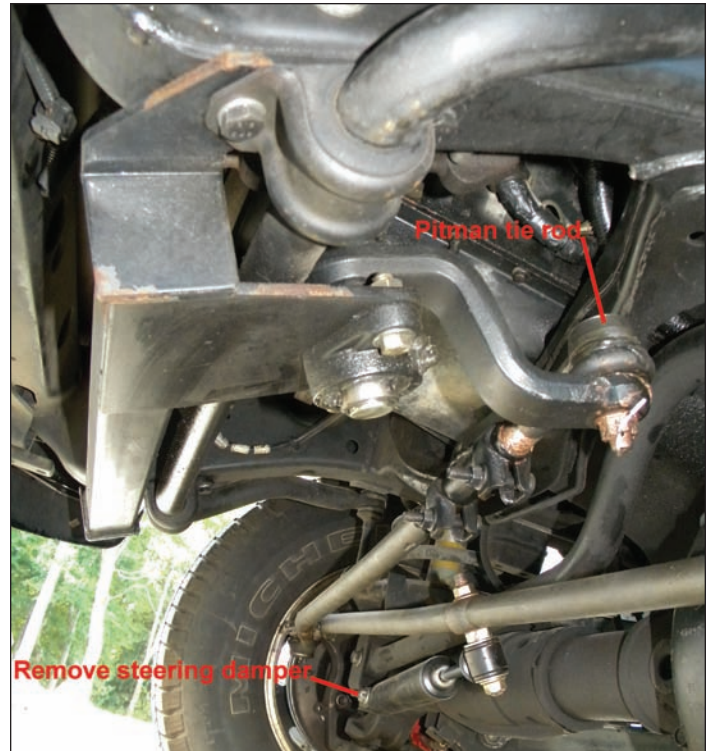
I had two jack stands with a capacity of six tons each and thought that would be plenty. After using my floor jack and placing my two jack stands under the frame rails just aft of the control arm brackets I decided I had too much weight too high! The truck was fairly steady but it was possible to move it around slightly by pulling on it with my hands. It only took a second for me to decide this wasn't secure enough for me to lie under so I purchased two additional six-ton jack stands and added them under the axle.

The jack stand configuration I used is shown below.



Once the truck is safely up on the jack stands and you are confident it is there to stay, remove both front wheels. The next step is removing the brake calipers. Plan to hang them from the control arm using a wire, a Ty-wrap, or a hook so that the brake hose is not stressed. Never drop the caliper or allow the hose to hold the weight of the caliper. The brake rotor should now slide off to reveal the bearing hub. (Unless you have a '94-'99, which is a different design.)

With the brake rotors off both sides, this is a great time to break this project down into two projects: tie rod ends and ball joints. (Well... maybe four projects. You may want to change the front differential oil while the steering components are out of the way.) I recommend removing the steering damper at the axle, the tie rod end out of the end of the Pitman arm, and the tie rods from each steering knuckle.



Remove steering damper.



This allows the entire steering tie rod system to come off in one assembly so the new components can be assembled to match. Care must be taken when handling the entire steering system as an assembly since it is heavy and the tie rods can allow the components to rotate and pinch your finger(s) between the various rods. (Ask me how I know.)

With the tie rods and steering damper off, now is a good time to get a drain pan under the front differential and remove the differential cover. To remove the differential cover, remove all the bolts holding it on and use a putty knife to separate it from the differential housing. If your oil needs to be changed, draining it now will limit the amount of oil that drips on the floor while the half shafts are removed. Remove all the residual sealant from the sealing surface on the

differential housing and differential cover, taking care not to allow any sealant flakes to get into the differential housing. Don't forget to take a clean rag and wipe the wear particles out of the bottom of the differential housing. Your gears and bearings will thank you.

Now for the bearing hubs! With the rotors off, half shaft nuts removed and the tie rod end removed from the steering knuckle, the fun of getting the bearing hubs off begins. Remove the ABS sensor if equipped and tie it back out of the way so the cable and/or sensor can't get damaged. Many pullers exist that connect onto the lug studs and push on the end of the half shaft in an attempt to get the bearing hub off. I don't like these since the reaction force is pushing the half shaft back into the axle. The factory service manual instructs one to back off of the four hub/bearing housing bolts 1/4-inch each. Then tap the bolts with a hammer to loosen the hub/bearing from the steering knuckle. Welcome to Fantasy Island! With 141,000 miles on my truck, the bearing hubs didn't respond to "tapping with a hammer."

The solution turned out to be a Lisle (LIS39300) Front Hub and Knuckle Separator from ToolTopia.com and my pneumatic impact hammer.



**Andy Redmond adds to Brent's story: I've used all the methods for stuck hub bearings and by far both the easiest and best method is the deep socket extension trick or Snap-On Tool DHP1. Use of the Snap-On tool wedged against a loosened bolt and against the axle tube while an assistant turns the steering wheel will pop them loose every time. Alternate the tool between the bolts to walk it off little bits at the time. In fact, I can even do it by myself, although it's a lot of running back and forth. Most DIY's don't have an air chisel or compressor with adequate power for Brent's pneumatic impact hammer task, plus you don't ruin what bit of hearing you have left, huh?**

**If you want, you can review my write-up on the Snap-On Tool DHP1 by looking at TDR Issue 69, page 120.**

Use the LIS39300 with your pneumatic hammer on the backed off bolts, maintaining a solid backup behind the impact hammer so the blows work the LIS39300 instead of reacting back into a loosely held hammer.

The face of the LIS 39300 is hollow so it won't beat up the hub/knuckle bolts. With patience and penetrating oil (and sometimes a little heat) the hubs will come out. With the passenger side knuckle turned to the right you run the impact hammer on the front two bolts, and with the passenger knuckle turned to the left, the rear two get the impact hammer. Opposite for the driver's side. One thing I noticed is that the housing must be "walked" off evenly. As you run the LIS39300 equipped impact hammer on the front two bolts the hub will come out on the front. Place a putty knife and then screw-driver in this gap so when you begin to hammer on the rear bolts it will help to force the hub out. Once the bearing hubs are off, gently ease the half shaft out of each side and lay them on newspaper. The trick here is to keep the spline and sealing surface of the shafts clean and scratch free.

With the bearing hubs and half shafts out, remove the nuts on the ball joints and the large retaining ring off the bottom ball joint as shown below.



Also note extensive use of penetrating oil, it really does help.

The next task is to get the steering knuckles off the ball joint studs. This job can be done easily with your pneumatic impact hammer and the Lisle stepped pickle fork kit (LIS41400) at [www.tooltopia.com](http://www.tooltopia.com). Run the largest fork between the knuckle and the axle yoke at the lower ball joint. Then take a sledge hammer and tap the knuckle near the upper ball joint. With patience and penetrating oil (maybe a little heat), the knuckle will pop free.

With the knuckle off both sides it is time to remove ball joints. For pressing the ball joints I ordered the QT1065 press set from [www.quad4x4.com](http://www.quad4x4.com). This kit had very clear instructions and worked great. The best feature of this kit is that all the different press stubs and receivers are numbered and the instructions list which ones to use for removing and installing both the upper and lower ball joints. Again, patience and penetrating oil will get the ball joints out. This is a great time to clean up the steering knuckles, especially the bearing receiver bore.

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## Reassembly

Now to put it all back together again. All components should be cleaned and mating surfaces checked for damage. Leave the grease fittings out of the ball joints until after installation, as the grease fittings are easily damaged.

The first task at hand is to apply anti-seize to the new ball joints and install them per the Moog instructions. I used Loctite C5-A copper based anti-seize lubricant, part number 51007. Again, I used the Quad 4x4 instructions for operating the QT1065 press.

Notice that Moog specifies that the ball joints are to be oriented with the grease relief INBOARD when installing. Take extreme care to get the ball joints started straight so that they don't 'dig in' and scar their receiver bores in the axle yoke. Verify that the lower ball joints are pressed in far enough to allow proper installation of the new snap ring which is included with each new Moog lower ball joint. The boot must be installed on the lower ball joint after installation. This is best done with a 1-1/2" PVC pipe coupling and a small sledge hammer. Make sure you have the correct orientation for the boot, grease relief notch to the inside, and place the boot onto the ball joint and push using the PVC pipe coupling to hold it in place. Take the side of the head of a small sledge hammer and bump the bottom of the PVC pipe coupling and the boot should install correctly. Verify that the boot is installed evenly all around.

Install both steering knuckles with anti-seize in the tapered ball joint stud bores; install the ABS cable brackets under the upper ball joint nuts; and torque all nuts per the instructions supplied with the Moog ball joints, paying particular attention to the torque sequence, intermediate torques, and final torques. Make sure to install the cotter pin on each ball joint stud/nut after achieving final torque.

**Andy Redmond adds to Brent's story: Another precaution about leaks: be careful not to put the axle in a bind with an extreme ball joint angle ('94-'99 trucks). A member that read Issue 53 e-mailed recently complaining of axle shaft seal leaks after installing upper adjustable ball joint sleeves. The fix was to use the lower trailing arm eccentrics and the adjustable upper ball joint sleeves in tandem to achieve about four degrees of positive caster versus his chosen value of six degrees. This allowed the spindle and axle to return to a more neutral and centered position, easing the stress on the axle seals. This was the luckiest guy ever. When he returned the adjustments to my recommendation, the seals stopped leaking. This is certainly not typical. Be forewarned: it's a big job to change these seals. On the driver's side the differential carrier has to be removed from the axle housing (labor guide—7 hours).**

The next step involves installing the half shafts into the axle tubes. Visually check on the passenger side by looking down the axle tube to see that the splined collar is in position, which it should be if you shifted into 4WD prior to beginning this project. If it isn't, you will see that it has dropped down and is too low to engage the passenger side half shaft. If the ring has fallen down, the procedure that follows will get you going again.

If you left the truck in 2WD, as I did, open the spline engagement housing or central axle disconnect (CAD) housing and place the spline collar onto the intermediate shaft's spline. You should clean

out the housing sump at this time. Leave the CAD open until after the passenger side half shaft and bearing hub are installed.

There are two tasks to pay close attention to when installing the axle's half shafts: one is to get the spline and the oil seal sealing surface super clean and then apply a light coating of grease; the second is to keep it clean during the installation process by rolling up a piece of heavy paper and putting it inside the axle tube. Ideally the paper should be stiff enough to support its shape and wide enough to stretch from the oil seal to outside the tube where it can be grabbed after shaft installation. The object here is to *never* allow the spline or shaft to touch the inside of the tube since rust or dirt particles could be picked up and deposited on the oil seal lip resulting in an axle oil leak, hence the need for the paper. Once the half shaft is installed the paper is removed by pulling and tearing, you'll want to verify that all the paper came out. I used the front and back cover off a Bass Pro Shops catalog, which worked perfectly.

The next step involves installing the bearing hubs in the steering knuckles. One of my observations when looking the truck over at the beginning of this project, was that while my bearings had no noticeable slop or loose motion in them, they made a clicking sound when rotated by hand. Given the suspicious clicking noise, and the fact that you can't disassemble the bearing hubs to inspect and repack the bearings, I decided to replace my bearing hubs. I chose the Timken HA590203 bearing hubs from Rock Auto since my truck has four-wheel ABS.

To install the bearing hubs first make sure the half shaft splines are clean and coated with anti-seize. Next, coat the bearing receiver bore in the steering knuckle with anti-seize and install the bearing hubs, ABS sensor hole up. Don't forget the brake rotor shield goes on with the bearing hub. Make sure to get all four bolts on each bearing hub to proper torque incrementally: top front, bottom rear, lower front, top rear.

With the bearing hubs installed, the hub shaft nuts can be installed, although final torque can't be achieved until the truck is back on the ground. Since the half shafts are installed, the front differential cover can be reinstalled and the differential filled with the proper lubricant.

Dodge doesn't use gaskets on the differential housing, but instead uses a gray colored sealant which must be completely removed with a razor scraper prior to reassembly. I chose to put the differential cover back on with a Felpro axle housing gasket, AutoZone part number RDS6095-1 for the Dana 60 front axle, since I'm not a big fan of the gasket-less assembly idea.

Now the tie rod end assembly can be replaced. I laid my entire assembly out on a table as it came off the truck and then laid the new parts next to the old ones. Pay particular attention to the amount of engagement the old rod ends have in the alignment adjusting sleeves. The object here is to build up the new assembly to exactly match the old one both with tie rod orientation and lengthwise adjustment. The truck will still require a front end alignment, but it is better to get as close as you can to save on tire wear enroute to the alignment. This is a great time to take a thread file and thoroughly go over each new threaded rod end prior to assembly. I found that the cardboard thread protector tube had come off one of mine inside the shipping box and had collected some dings in a couple of the threads. These nicks make for hard turning adjustments during front end alignment.

Once the new tie rod assembly has been built up it is time to install it onto the truck. Prepare the tie rod stud receiver hole in the Pitman arm and in both steering knuckles by cleaning them, inspecting for cracks or other damage and coating it with anti-seize. Carefully lift the assembly to the truck and install into the steering knuckles and Pitman arm. Verify that everything looks right and then install the steering damper. Install all tie rod stud nuts to proper torque and install the cotter pins.

This concludes the assembly of the steering system. Review every aspect of your work to make sure that all components are installed correctly and that all proper torques were achieved during installation.

Once satisfied that everything is in order reinstall the front brake rotors with anti-seize on their bores and install the brake calipers. Make sure that the rotors are clean and lubricant free. Install both front wheels and place the truck back on the ground. Now comes the torquing of the bearing hub / half shaft nuts using the 1-11/16" socket and following the Timken installation instructions for proper torque. After final torque is achieved, install the cotter pins.

Parts used on this front end rebuild are:

| Description       | Manufacturer | Part number | Quantity |
|-------------------|--------------|-------------|----------|
| Steering damper   | Monroe       | SC2964      | 1        |
| Tie rod end       | Moog         | ES3526      | 1        |
| Tie rod end       | Moog         | DS1462      | 1        |
| Tie rod end       | Moog         | ES3527      | 1        |
| Tie rod end       | Moog         | DS1460      | 1        |
| Ball joint        | Moog         | K7394       | 2        |
| Ball joint        | Moog         | K7397       | 2        |
| Track bar         | Moog         | DS1413      | 1        |
| Bearing hub w/ABS | Timken       | HA590203    | 2        |

**Andy Redmond adds to Brent's story:** Many members may also have severely worn upper and lower arm trailing bushings, which can also allow unwanted fore and aft axle movement. Replacement bushings are available from Dodge and the aftermarket to re-bush the trailing arms. This is most easily accomplished by removing the trailing arms, then removing/installing the bushings with a shop press. Urethane replacement bushings (Energy Suspension) are available, but these require periodic grease lubrication to prevent squeaks and may add harshness to the ride. (Urethane does not flex like a rubber bushing.) My favorites are the beefy lower links from Solid Steel Industries. The SSI Lower Adjusting Links are recommended for heavy off-road use and ease of caster adjustment. Modifications are necessary to use these on the '94-'99 trucks, as the installer must provide inner bushings to bush the link's inside diameter down to the OEM fastener shanks.

Conclusion

Well, gang, does that conclude the correspondence on steering woes and the solution to the Second Generation truck's death wobble? Since most all of the components were replaced, I would hope the answer is "yes."

**Brent Boxall**  
TDR Member

*Editor's note: My thanks to Brent for the complete write-up covering Second Generation steering problems and to Andy for his additional Shop Floor insight. To close out this article, please make note of Andy's updated alignment specifications for '94 to current 4x4 Turbo Diesel trucks that is shown below.*

PREFERRED ALIGNMENT SPECIFICATIONS UPDATE  
by Andy Redmond

| YEAR                           | TOE                                | CAMBER             | CASTER                    | COMMENT                                                                                                                                                                                                                               |
|--------------------------------|------------------------------------|--------------------|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1994-2002                      | 0 deg. or<br>(+0.10 total toe in)  | 0 deg. (±.50 deg.) | 3.5-4.0 deg.<br>positive  | '94-'99 trucks will require an offset fixed or adjustable upper ball joint sleeve to obtain these specifications (caster). Trucks needing camber adjustment will also require sleeves, and the '00-'02s upper adjustable ball joints. |
| 2003 to present                | 0 deg. or<br>(+0.10 total toe in)  | 0 deg. (±.20 deg.) | 4.0-4.5 deg.<br>positive  | 0-2" Leveling kits seem to like about 5 to 5.25 deg. pos. caster.                                                                                                                                                                     |
| 2003 to Present<br>Cab Chassis | 0 deg. or<br>(+0.020 total toe in) | 0 deg. (±.20 deg.) | 3.75-4.0 deg.<br>positive | These differences are likely due to these vehicles being used at GVWR capacities.                                                                                                                                                     |

# Truck Detailing

ISSUE 68

## NEW AGAIN: MACHINE POLISHING FOR MORTALS

by Doug Leno

Six years ago, when I took delivery of my 2004 Turbo Diesel, my service manager pulled me aside and admonished, “Doug, I didn’t realize you had special-ordered black clear coat. You’re going to need a good carnauba wax...”

This comment propelled me into the emotional world of retail detailing products. Following the service manager’s advice, I consulted as many forums and blogs as time allowed, just to get a feel for what people were actually using and why. I also consulted TDR Issue 43 (page 70) where member Don Mallinson presented “Confessions of a Detailing Fanatic,” a comprehensive article filled with instructional tips from his own professional experience. As a three-time national concours champion and owner of his own detailing supplies business, Don is well qualified to speak about this subject, and his article should be considered required reading.

My initial research in 2004 produced a small investment in wash, clay, wax, and hand polishing products from various manufacturers, even some with funny sounding names. Most of these have proven effective. As a bonus, I found the emotion in various marketing campaigns and internet posts to be quite entertaining. As the Editor noted in Issue 43 (page 77):

...I can tell you that wax choice ranks right alongside lube oil as emotional, enthusiast-crazed owners verbally spar on the topic. Perhaps both of these subjects are analogous to discussions on religion—you can talk about the topic until you are blue in the face, but seldom will you effect a change of devotion or mind.

I found that the above applies to just about every detailing product known to man, but especially polishes and glazes, detail sprays, and wash products. Phrases like “bringing out the emotion in the paint” and references to car wash soap as “shampoo” are among my personal favorites. In fairness to enthusiastic loyalists, however, I’ll point out that part of the above-mentioned devotion comes from regular use. Most of us are comfortable with what we have purchased, know, and use regularly whether the product has a funny sounding name or not. The rest, however, is just marketing.

### The Results of Neglect

I learned early on that regular hand polishing was more work than I could keep up with and, sadly, I have accepted less and less paint perfection in exchange for saving my elbow grease over the years. The battle scars of work and the road have accumulated, on top of the swirl marks that originated from the factory and from dealer prep work, plus a few that I caused myself. Under the right lighting conditions, the result of this neglect is painfully obvious, as shown in figure 1: Direct sunlight is very unforgiving!



Figure 1: Scratches and swirls are obvious on black paint in direct sunlight.

Water spots have also been a problem for me, in spite of using soft water for every wash. The effects of roadside sprinklers, rain, infrequent waxing, and washing the truck in the hot sun have produced a substantial accumulation on the glass as well as the paint. Figure 2 is a macro photograph of my passenger-side door panel, showing severe water spotting. The photo is a little closer and more dramatic than what the naked eye can see, but not by much.

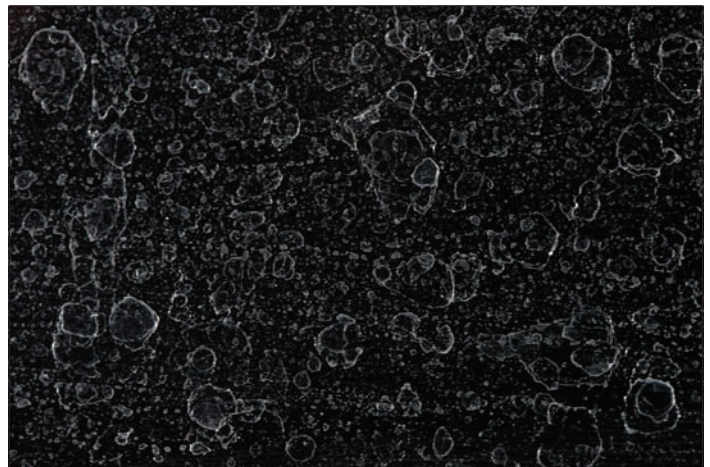


Figure 2: This macro photograph of water-spotting on my Turbo Diesel is only a little more dramatic than what can be seen with the naked eye. Black shows everything!

## Research and Scope of the Project

It was time to renew my enthusiasm for paint care, this time with the additional investments as required to correct the scratches, swirls and water spots that hand polishing could not correct, along with a resolve to lighten the workload with a machine-based system. I was immediately faced with a bewildering array of choices: Should I use polish #5432 or perhaps the medium-fine compound #2 followed by the amazing super-glaze? Should I get the dimpled blue polishing pad or the smooth orange one? Would I need to use the purple or gray pads, or would the red and white ones do? Should I use foam, wool or sheepskin? I started looking for a simple system that wouldn't require a cheat sheet or memorization work, and one that I didn't have to design myself.

In the matter of choosing a polisher, the Issue 43 article proved quite useful in its endorsement of random orbital machines. Unlike the circular polishers that produced the swirls I was trying to get rid of, today's orbital polishers offer a much safer mechanical action (described later) which vastly reduces the chances of damaging the paint. Issue 43 speaks highly of a particular machine, the dual-head Cyclo model 5, but for the \$300 price tag I wondered if I might find two single-head polishers, one for larger areas and one for smaller areas.

Further research into polishing machines revealed a few reasonably-priced alternatives, some of which were rebadged orbital sanders. I discovered a whole subculture of detailing enthusiasts dedicated to certain variations of a popular machine known as the Porter Cable 7424. This machine has a loyal following, and has spawned an aftermarket industry of its own for such things as custom backing plates and counterweights. The 7424 is available in various forms from a wide variety of sources.

For this project, I turned to Griot's Garage, the folks that send out those great little tips mentioned back in Issue 43. I had been using some of their products since my truck was new, and decided to check out their machine polishing system. I discovered the simplicity I was after: There is only one (orange foam) polishing pad, and a set of polishes with sensible names: Machine Polish 1 (most aggressive), Machine Polish 2 (medium aggressive), and Machine Polish 3 (least aggressive/final polish). Moreover, I was able to understand Griot's terminology without consulting a glossary: No need to define words such as "glaze" or "buffing" because these terms are not used. One simply applies the polish with a pad, and removes the same with a suitable cloth. Simple.

I decided to invest in the Griot's machine polishing system for my Turbo Diesel, but at the same time look into a few unanswered questions I had. For example:

1. While the Griot's system offered a simple polish system using one pad, I was surprised at the number of micro-fiber cloths they offered, each of a different color. Are they all necessary?
2. Costco sells micro-fiber cloths at a very attractive price. Are these okay to use on my paint?
3. Would the Griot's 3" random orbital (\$90) together with their 6" random orbital (\$130) be a suitable alternative to the \$300 Cyclo polisher?
4. Would the polishing system also remove water spots on glass?
5. Would I be able to add anything to the debate over using dish soap for the wash step?

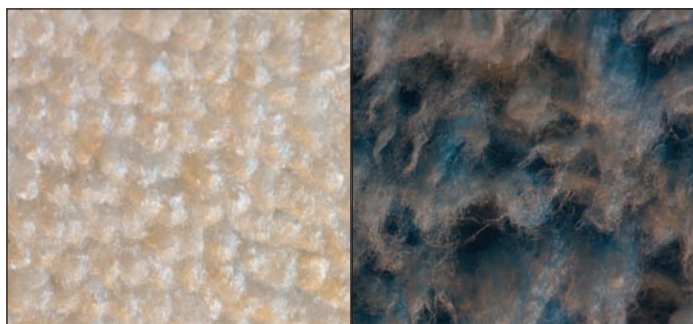
Question number 5 above has remained unsettled in my mind, mostly because qualified experts have lined up on both sides of the issue. You can blame my analytical nature, but I haven't "seen the data," if you will, so I constructed an experiment to answer the question myself and will share the results later in this article.

## The Micro-Fiber Question

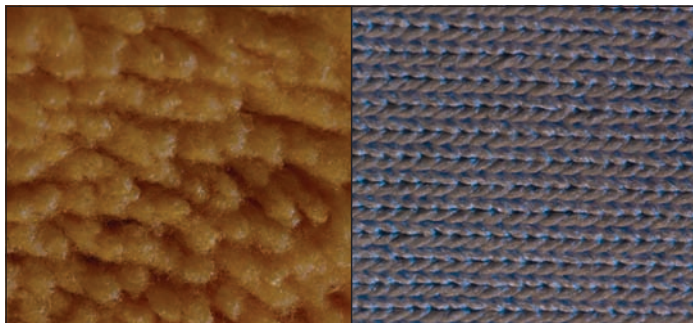
When the Griot's system arrived, the first thing I did was to examine the different micro-fiber cloths and compare them with what I bought at Costco. Griot's included the following;

1. White cloths with short fibers for removing wax
2. Blue cloths with very long fibers for removing "Speed Shine" detail spray
3. Yellow cloths with medium-length fibers for removing polish
4. Blue cloths with a very tight weave for cleaning glass
5. Yellow waffle pattern cloths for drying

The following five photographs, all taken at the same magnification factor, illustrate the fiber and weave differences between each of the Griot's micro-fiber cloths.



**White: short fiber is used in wax removal.**  
**Blue: a very long fiber is used for Speed Shine detailing spray.**



**Yellow: a medium long fiber for polish removal.**  
**Blue: this very tight weave avoids streaking on glass.**



**Yellow waffle: long fibers in waffle pattern holds more water.**

At first I was skeptical that so many different fiber lengths and weave designs were really necessary, and I was even reluctant to accept the need for five different cloths. However, I soon discovered that each weave pattern is designed for and (loosely) color coded to match the product for which they are intended. I maintain great respect for those who prefer the same type of cloth for multiple applications; I just came to appreciate how well the Griot's cloths were matched to their respective tasks.

What about the Costco microfiber cloths? The folks at Griot's acknowledged that the vast majority of micro fiber cloths are manufactured in China, including some of theirs, but insisted that not all cloths are created equal. I decided to test that theory with my camera's macro lens, and discovered an interesting distinction shown in figures 3 and 4: The Costco cloth tended to come apart more easily at the edges and exposed a hard (melted) component that I thought might even scratch my paint. While setting up to take these photos, I also noticed that the Costco cloth shed some fibers onto my dark backdrop. Other than those two details, the yellow Costco cloth I tested was similar to the Griot's white cloth used for removing wax. Your mileage may vary, of course, but I decided not to use the Costco cloths on my black paint. They're great for interior work like cleaning the dash or the carpet, however.



**Figure 3: Costco cloth edge weave. A hard, melted portion on the corner (circled) has separated from the cloth, introducing some risk of scratching the paint. This cloth also shed some fibers when I shook it, unlike the Griot's cloth.**



**Figure 4: Griot's white wax-removing cloth has a well-controlled edge weave, and did not shed any fibers. There is a melted portion to keep things from unraveling but it is tightly contained.**

## Speed Shine?

Griot's "Speed Shine" is an interesting product, especially considering Don's advice in Issue 43:

Speed shine or spray shine products can be very bad for the health of your paint! I recommend using these products only to remove fingerprints or in an emergency at a show...

This is sensible advice, especially for detail sprays with insufficient lubricity and used with short-fiber cloths. I was glad to find that Griot's does not promote the use of Speed Shine for general cleaning, but they do promote it for removing light dust and road dirt in between washes. I found its lubricity and optical properties to be quite good, and that it can lift small quantities of dirt from the surface. The Griot's matched blue Speed Shine cloth has the longest fibers of any I have seen in the automotive microfiber world, and traps dirt extraordinarily well. Due to the combination of Speed Shine's lubricity and the very deep, high-loft fiber design of the blue cloth, I've been able to use Speed Shine to remove small amounts of dirt without introducing any additional scratches or inner emotional conflict. It contains no silicones, and is compatible with carnauba-based waxes and Griot's own paint sealant (a polymer-based alternative to carnauba). While it is no substitute for wax, I found that Speed Shine does extend the interval between wax jobs, just as Griot's claims.

## The Work Begins

The Griot's polishing system is designed around clay-based abrasives that break down under continuous use. This makes the system safe for non-professionals because there is virtually no danger of damaging the paint. I found no learning curve either: Within the first minute of use, I was comfortable. Some experimentation was needed to learn how much product to apply to the pad (to avoid making a mess), but that skill came very quickly as well. I made good use of the blue, 3M masking tape to cover the trim.

I used the standard wash ➡ clay ➡ polish ➡ wax routine, which, as you might notice, is absent a "glaze" step, considered important by many in the industry. However, every time the term comes up it needs definition, and I was determined to carry out this project without a glossary so I didn't use a "glaze." Or did I? I will credit Griot's Garage with one additional simplification of the polish process: Machine Polish 4. Call it a polish or call it a glaze; it contains the mildest abrasive of any polish in the Griot's system. Used prior to waxing, it is necessary only to achieve that last bit of perfection, especially in competition and/or for dark colors before applying a carnauba-based wax. I decided to use it on my black paint.

## Clay

I used Speed Shine as the lubricant for the clay. It's not that expensive, has the right lubricity, and works well. I could have used a light concentration of Ivory Liquid, as Don's article suggests, but truth be told the Speed Shine was convenient and I didn't want to deal with yet another chemical solution or spray bottle. I credit Griot's Garage for not introducing a separate lubricant with a fancy

name just for clay: After all, they could have re-packaged Speed Shine with a slightly different color and called it “enhanced clay lubricant” or something.



Figure 5. Griot's Clay bar and Speed Shine.

### Polish

Because this was my first machine polishing experience, I followed Griot's conservative advice and started with their “Machine Polish 3”, their least aggressive polish, which is often used as the final polishing step prior to wax for light colors and daily drivers. I did this to get a feel for the machine itself, how much material to apply, and the overall effectiveness on my paint. I soon discovered that this polish was no match for my scratches and water spots! Being the conservative analytic that I am, I tried the next aggressive product, Machine Polish 2. That didn't work either, which meant that I had to start with their most aggressive product, Machine Polish 1, and work my way back through the numbers.



Figure 6. Machine polishing with Griot' orange polishing pad and “Machine Polish 3”.

Note that a polish removal step is necessary in between polish steps, to avoid cross-contamination: You don't want residue from a more aggressive polish left over while you are trying to produce a perfect shine. This step is also where I learned not to put too

much polish on the pad! If you haven't applied too much, this step is easy using the orange polish-removal cloths. I have to admit I used a little water spray from time to time to help me cut through the polish residue.

Separate orange polishing pads are used for each polish type, for the same reason. I simply marked each one on the side with a Sharpie pen to make sure that each pad was always used with the same polish. After use, I washed them in clear, warm water and stored them in the cabinet.

I have concluded that the four-step Griot's polishing system was designed for those who want professional looking results, but don't want to become professionals. Yeah, that's me. I like the Griot's polish numbering system because it tells me what I need to know without making me consult a glossary to pick the right abrasive, and it doesn't require a spreadsheet for me to pick the right polishing pad.

### The Griot's Random Orbital Machine Polisher

In a direct-drive circular polisher, the polishing pad simply spins around a shaft like a grinding wheel, which means that the outer portion of the pad does more work than the inner portion. Considerable skill is required of the operator to guarantee even coverage and to avoid burning the paint.

To visualize the action of a random orbital machine, imagine grasping a round polishing pad in one hand and waving it around in small, circular motions (orbits). In addition, imagine that you could slowly rotate the pad in your hand at the same time. Not many of us have that kind of dexterity, but this is exactly what a random orbital polisher does, only at nearly 7,000 orbits per minute. Under the power of the motor, the entire backing plate vibrates or oscillates in small circles (instead of spinning), thus moving the entire pad instead of just rotating it. A suitably-placed counter-weight insures that the machine doesn't jump out of your hand. The backing plate itself is free to spin around its shaft, and this allows the pad to rotate slowly at the same time. The Griot's detailing handbook (available as a free download from their web site) contains a good illustration of this complex motion, which I have reproduced with permission in Figure 7.

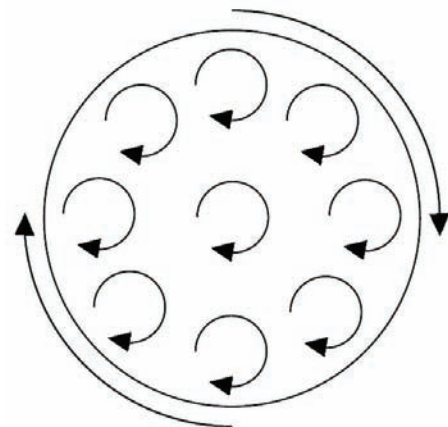


Figure 7: The mechanical action of a random orbital polisher combines pad oscillation (small circles) with pad rotation (large circle). Used with permission.

To ensure even coverage using a random orbital machine, Griot's recommends simple back-and-forth, up-and-down motions, as I did in figure 6. Also, to avoid splattering polish all over the place, be sure to start and stop the machine with the pad resting on the paint!

Typical in the industry for random orbital (sometimes called "dual action") polishers is a 5/16" (or so) orbit diameter which determines the polish area that the motor has to work against. According to my measurements, the Griot's machine falls in line with the rest of the industry, but its 850-watt (approximately 7 amp) motor appears to be substantially more powerful. Accustomed to 4.5 Amp (or so) motors for other machines such as the Porter Cable, I wondered if this would translate to additional power "to the paint," so I experimented by bearing down on the polisher in an attempt to stall it. This takes an impressive amount of force! By the time I got the polish pad to stop rotating, I was afraid of damaging the steel body panels themselves, so I stopped the experiment. At that point, the pad was still orbiting (but not rotating) and the motor itself never stalled. From this I concluded that there is substantially more power available in this polisher than necessary for the job.

### Final Wax, and Results

Having always applied wax by hand, I was intrigued with the idea of applying wax by machine. This requires a different pad of course—one that is very soft and has the right foam structure to transfer wax to your paint instead of just absorbing it. Griot's red foam wax pad works well for this, and I am now a convert to machine waxing. Here again, some experimentation is required to determine how much product to use without making a mess; the more you put on, the more you have to remove! As with polish, there are certain areas where a machine can't go, but with the combination of the 6" polisher and the 3" polisher I covered a lot of territory by machine. For those really hard-to-reach areas, I took the pad off of the machine, attached it to a Velcro adapter, and applied the wax by hand.

The results I obtained are best illustrated photographically, as words do not do justice to the improvements I obtained. Figure 8 shows the clarity and shine in the reflection of my wife's chrysanthemums in the rear, passenger-side door.



Figure 8: Paint perfection achieved with 4-step machine polish followed by "Best of Show" wax.

Figure 9 shows my success in a dramatic close-up photo. I will point out that I took this in direct morning sunlight which greatly exaggerated the swirl marks and scratches, but the photo is fair to both sides of the line! To obtain this result, I put a strip of blue 3M masking tape down the passenger-side rear quarter panel of my truck (the same panel shown in figure 1), providing a clean separation between what I polished and what I didn't. The area in the left side of the photograph has been washed, clayed, washed again, and then treated with Speed Shine. The right side of the photograph represents the following steps:

- Wash
- Clay
- Machine polish 1 (most aggressive)
- Machine polish 2
- Machine polish 3
- Machine polish 4 (least aggressive)
- Best-of-Show wax
- Speed Shine

As you can see, there is orange peel inherent in the factory paint, but there's nothing I could do about that!

**Editor's Note: Yes, you could address the orange peel, but removing orange peel by wet-sanding the paint with 1000/1500/2000 grit paper and then starting the 1/2/3/4 process requires there to be a confidence in the thickness of the clear coat. Removing orange peel on a factory paint job is sometimes tricky. Too much effort and the clear coat is gone...ask me how I know.**

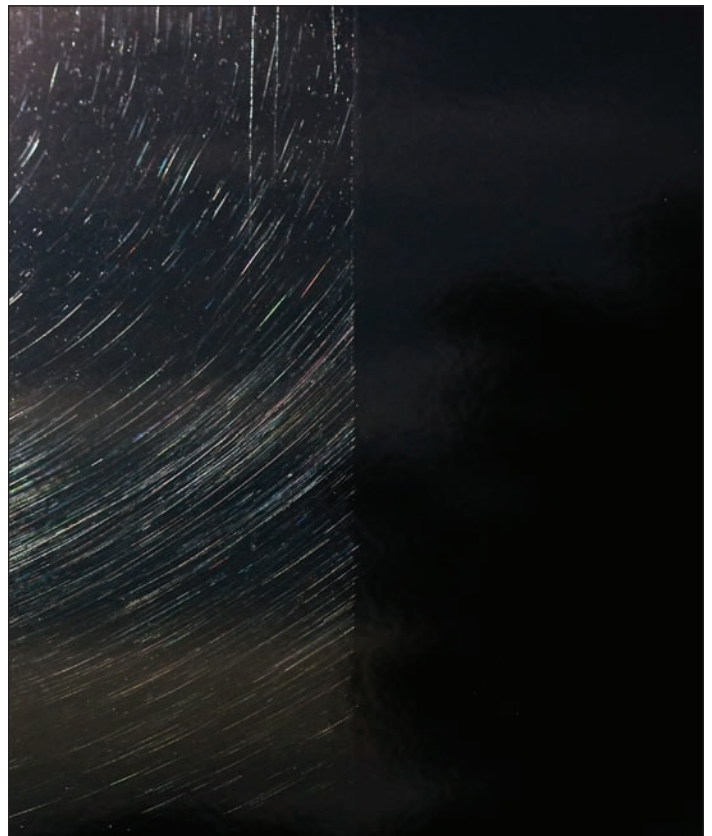


Figure 9: The right side has been machine polished, while the left side has not.

## Glass, Trim, and the 3" Random Orbital

I mentioned earlier that water spots had accumulated on my glass surfaces, and that hand polishing was ineffective against them as well. My rear window was particularly awful because the canopy shell I installed prevented any attempts at cleaning it. I decided to remove the shell and polish the glass.

Outfitted with a (white) glass polishing pad and Griot's glass polish, I attacked the rear window with Griot's 3" orbital, as shown in Figure 10. The results, shown in figure 11, are spectacular; the top portion of the photograph has been polished, but the lower portion has not. The reason that the line between "polished" and "unpolished" is not very straight is because I had not yet thought of the blue 3M tape trick!



Figure 10: Polishing glass using the 3" random orbital, the white glass polishing pad, and Griot's glass polish.

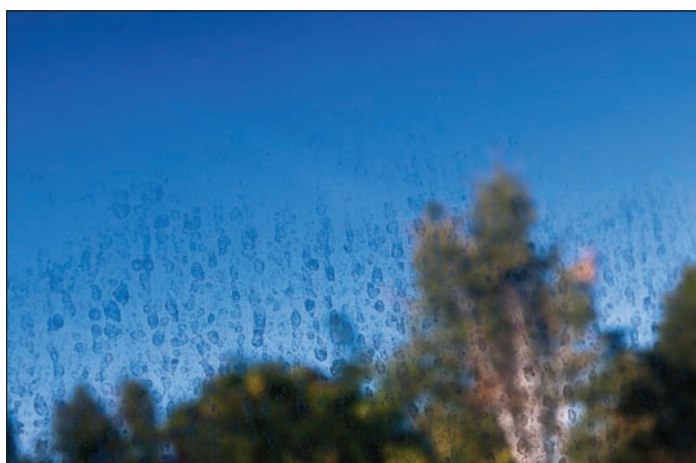


Figure 11: My rear window after polishing.  
The upper part of the photo used to look like the lower portion.

Another use for the 3" orbital is for cleaning trim. Over the years, my truck has endured the sacrifice of a great many small, winged creatures, and without prompt and regular attention this residue is very difficult to remove from textured trim. The solution? Griot's yellow scrubbing pad for the 3" random orbital. Using the blue 3M tape trick mentioned earlier, I isolated the left side of the mirror from the right to show the effectiveness of the orbital, as opposed to hand scrubbing with the same pad. I had to pull out every trick in the Griot's arsenal to get things clean: The entire mirror was first treated with Griot's Rubber Prep (a strong detergent/surfactant) and then cleaned with Griot's Rubber Cleaner using the 3" yellow scrubbing pad. Finally, I used Griot's Vinyl and Rubber Dressing on the whole surface to restore the black appearance. If you look closely at figure 12, you can see that the right-hand side of the mirror is just not clean: That's where I took the yellow pad off of the 3" orbital and scrubbed by hand as best I could.



Figure 12: Rearview mirror after using Griot's 3" random orbital fitted with the yellow scrubbing pad (left side). The right side was cleaned with the same pad, only by hand.



Figure 13. Griot's 3" random orbital with a versatile collection of pads. From left to right: yellow scrubbing pad (installed), orange polishing pad dedicated to "machine polish 4", red waxing pad dedicated to "best of show" wax, and finally the white, glass polishing pad.

## Dish Soap Shoot-Out

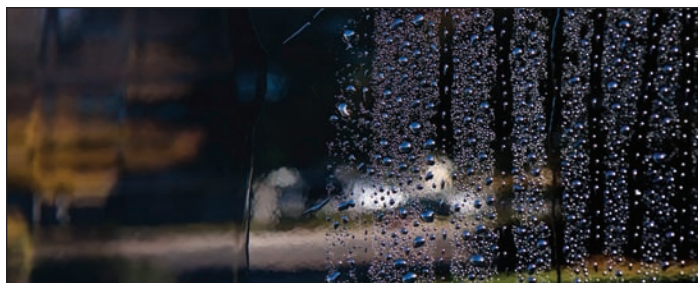
I left the washing phase of this project until last in order to address the question of using dish soap on waxed paint. I'll acknowledge up front that my results are going to please some while others will shake their heads, but all I can say is that what I present here are plain, honest results. The photographs I took have not been altered to benefit any particular result! For this experiment, I purchased bottles of Ivory liquid and Palmolive dish soap to complement the bottle of Dawn that was already under the kitchen sink.



**Figure 14. Ivory, Palmolive, and Dawn dish soaps pitted against Griot's Car Wash.**

With my truck freshly waxed with Griot's "Best of Show" wax, I got out the blue 3M tape again and put a stripe down the middle of that section of the paint showing off my wife's chrysanthemums. I prepared two wash buckets and separate, freshly-washed mitts. I filled one bucket with the recommended concentration of Griot's Car wash and the other with a sudsy solution of Dawn. I tested both solutions by hand to sample the suds and the lubricity.

On the left side of the tape, I took the mitt from the bucket containing Dawn, then washed and rinsed the area five times (to simulate five washings), with the motions I normally use. On the right side of the tape, I took the mitt from the Griot's Car Wash bucket, and washed that area five times, just as I had done to the left. After removing the tape, I sprayed a fine mist of water onto the entire panel and grabbed my camera. The water beaded up astonishingly well on the right side (after washing five times with Griot's Car Wash), and not at all on the left (after washing five times with Dawn).



**Figure 15: A solution of Dawn dish soap (left) does not allow the same water beading performance as Griot's Car Wash (right) after washing five times. Liquid soaps from Ivory and Palmolive were tested as well, with similar results.**

I then took the dish soap mitt inside and rinsed it thoroughly (in soft water) to eliminate cross contamination before changing soaps. I polished again with Machine Polish 4 (the least aggressive compound) and re-waxed with Griot's "best of show" before repeating the experiment with Ivory liquid. Finally, I repeated the same procedure with Palmolive. The photograph in figure 15 shows the first result I tested, which represents the use of Dawn, but both the Ivory and the Palmolive produced the same result, with Ivory only slightly out-performing the other two. Incidentally, the fine water spray I used for the experiment was "soft" water, meaning it had been treated with an ordinary ion-exchange water softener, and this may have influenced the result. Due to its lower surface tension, softened water has a tendency to "sheet" more and to "bead" less.

My conclusion? Consistent with Don's assessment, I found the lubricity and suds performance of the Ivory liquid I purchased to be better than Dawn or Palmolive. However, as a practical matter I found it to be no better than Griot's Car Wash. To be sure, Ivory is the only dish soap I would recommend for washing a vehicle, assuming of course that their formula stays the same and that the flavor I tested is available in your area. However, if you really want to maximize the interval between wax jobs, consider a product like Griot's Car Wash. Its lubricity and suds performance is excellent and the data show that it is by far the easiest on carnauba-based waxes like Griot's "Best of Show."

It would be good to point out that pampering your wax may not be the objective of every wash. For example, if you are going to clay and polish anyway, then you surely don't care about extending the interval between wax jobs, and in these situations why not reach for the Ivory? Moreover, if you already have a clean solution of Ivory available, I see no reason to avoid using it for clay lubricant as well, as Don suggests. It's just a matter of personal preference, and how many different chemical preparations you want to deal with. For example, I already have Griot's Car Wash and Speed Shine ready to go in my garage, and it's just not worth the hassle for me to add something else to my arsenal.

While we're on the subject of washing, here are my thoughts about car wash places: In my experience, the automatic, drive-through car washes are either ineffective or too destructive, so I try to avoid them. On the one occasion when an automatic car wash successfully cleaned my truck, the heated dryers at the end of the tunnel were so powerful they ripped the bug deflector off! I stay completely away from the ones that touch: you never know what kind of grit was left behind by the vehicle in front of you. I do like the spray-it-yourself places, however. I've even been known to bring my wash bucket, mitts and cloths with me, but the owners generally frown on that, even if there is no one waiting behind you. Be careful with the high pressure sprays, however—they can inject water under the chrome plate on trim pieces if you spray too close.

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## Machine Polish 4 for New Water Spots

I mentioned before that the Griot's numbering system helps me decide which polish to use, depending on the condition I am out to correct. After finishing this project I noticed water spots again, apparently from rain and road spray, which had accumulated over several days. Washing and following with Speed Shine didn't work, so I reached for Machine Polish 4 which did the trick. Figure 16 is a photograph of the gap between the cab and the bed on the passenger side—the left side of the photo shows the water spot accumulation that washing and Speed Shine could not correct. The right side shows the effectiveness of Machine Polish 4.



**Figure 16: Machine Polish 4 (right side) takes care of new water spots that washing and Speed Shine could not.**

- Micro fiber cloths can be very useful, if the weave matches the task. For example, Griot's blue cloths for glass have such a tight weave they are closer to newsprint (often used for glass) than any other cloth I've seen.
- The judicious use of Speed Shine detail spray works wonders, especially right after a wash because it has the right optical properties and the right lubricity. It can also be used as a clay lubricant, and even for small amounts of dust in between washings.
- I see no problem using a solution of Ivory liquid for clay lubricant, but if you already have Speed Shine around, it may not be worth the trouble.
- Make sure to put a grate in the bottom of your wash bucket so that your wash mitt doesn't pick up the dirt you already removed from your truck

**Doug Leno**  
**TDR Writer**

For more information on the products mentioned in this article, contact:

**Griot's Garage**  
[www.griotsgarage.com](http://www.griotsgarage.com)

## Next Steps, Conclusions and Tips

I have used Griot's products throughout this project, mostly because I learned to trust them over the years, but this writer understands that "your mileage may vary" and that a great many other solutions and preferences are in use today. The main objective of this project was to illustrate my own experience in finding the right polish system that works for me. I like Griot's simple product naming approach, and the bottom line is that I get good results. The system is very safe and provides instant success for non-professionals like me. Like other random orbital based systems, however, it won't correct badly damaged paint with very deep scratches or chips that penetrate through to the primer, all of which require a professional paint job. On the other hand, there are other paint-correcting opportunities still ahead of me, such as severe (but not complete) damage to the clear coat, but these will have to wait until I'm ready to learn wet sanding.

One important lesson learned during this project: Even with a machine polisher, maintaining a black paint job is a lot of work! Here are some additional conclusions:

- Like the experts say, fluorescent lighting is great for inspecting paint, but if you really want to show swirls and scratches in dark paint, catch the evening or morning (low-angle) direct sun!
- Ivory Liquid dish soap is a good alternative for wash if you don't mind waxing more often. Otherwise, use a high-lubricity, high-suds product like Griot's Car Wash.

# Clutches

ISSUE 63

## CLUTCHES

by Gary Croyle/Perfection Clutch

Clutches: the source of tire-smoking shaft-twisting controlled power; or a completely misunderstood, frustrating device that you swore you would never own one of those again kind of part? Which is it for you?

In this article, I'd like to discuss how clutches work, explain some of the terms that we use in the clutch business, talk about the proper installation of a clutch and give you some tips for longer service life. Here goes...

### The Components

To understand clutch terminology you'll need to have a picture of the five key clutch components: the flywheel, cover assembly, clutch disc, release bearing and the release system.



Flywheel



Cover Assembly/  
Pressure Plate

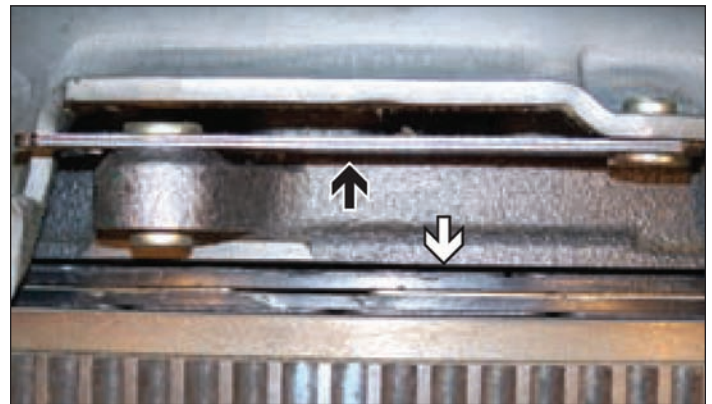


Clutch Disc



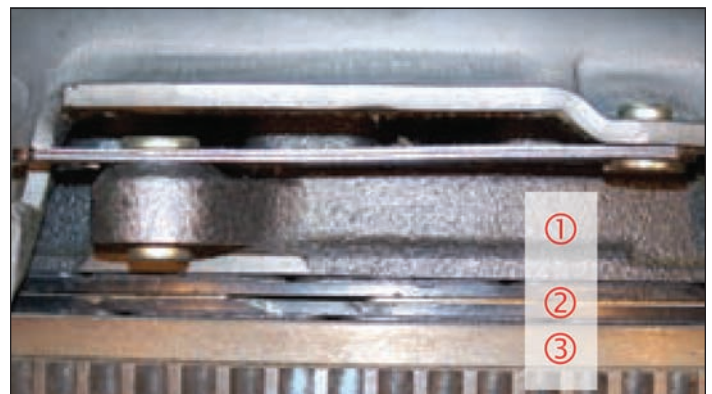
Release Bearing

With the picture below, you can visualize how uncomplicated the principle of operation is. Let's use as an example disengaging the clutch as you stop the truck. Push down on the truck's clutch pedal and the master and slave cylinders push in against the tips of the diaphragm spring. The clamping pressure is released, and the drive straps pull the pressure plate casting away from the clutch disc. The clutch disc floats on the transmission's spline and comes to a stop as the transmission's internal parts cease to rotate. The clutch is now released. (But, remember, your foot is still pushing the clutch pedal, with the pedal down on the floor.)



Released clutch. The black arrow points to drive straps on the pressure plate. The white arrow points to the gap between the clutch disc and the pressure plate.

Let's engage the clutch. As the pedal is allowed to come up, the pressure plate casting moves closer to the disc. As it touches the disc, the input shaft starts to turn and the truck begins to move forward. As the engagement process is completed, all of the clamping force is being applied to the disc and a clutch sandwich is now made up of the flywheel, disc and pressure plate.



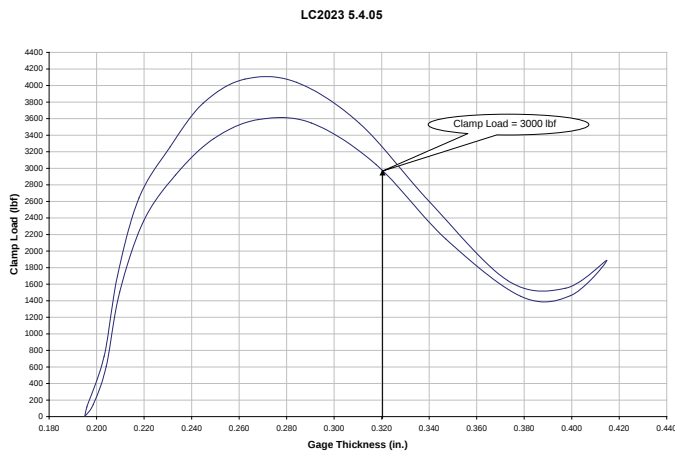
Engaged clutch.

Pressure plate ①. Clutch disc ②. Flywheel ③.

Simple, yes? Push clutch pedal in to disengage. Let pedal out to engage. Now let's move on to some of the technical terms that are used to describe clutch testing and operation, clamp load, release load and plate lift.

### Clampload

Clampload is the force usually expressed in pounds (lbf = Pounds Force) that the clutch cover assembly (also known as a pressure plate) exerts against the friction material of the clutch disc. We need clampload to prevent the disc from slipping in the sandwich that is made up of the flywheel, disc and clutch cover assembly. One of the unique design features of the modern diaphragm clutch cover is that the clampload increases as the clutch's friction disc gets thinner. As the clutch disc approaches its worn out thickness, the clampload returns to its original clampload. In the graph below, the top curve represents the force required to press the casting down against the diaphragm spring and the bottom curve is the force returned to the pressure plate by the diaphragm spring to clamp the disc. The force at the new disc thickness and when the disc is worn out are the critical data points. In this example the clampload is 3000 lbf on a new disc and with the disc (friction material) worn by .080" the clampload has returned to 3000 lbf. But, notice that in the middle of the wear cycle, the clampload has actually increased by 600 lbf.

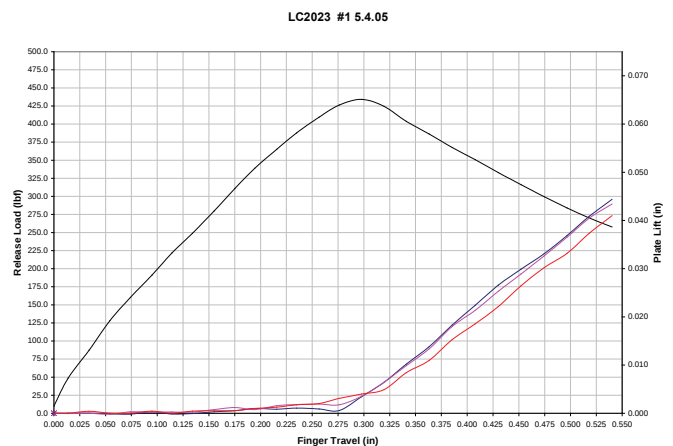


### Release Load and Plate Lift

These concepts are a little easier to visualize. To plot release load and plate lift the clutch is mounted in an installed condition on our clutch testing machine and then released by pressing down against the diaphragm spring tips and plotting the distance traveled by the release bearing versus the force required.

With a diaphragm clutch, the force peaks then drops off. It has the "overcenter" feel that we are so accustomed to. In this graph, the peak release load at the bearing is about 430 lbf, dropping off to about 275 lbf when it is fully released. With a diaphragm clutch, as the disc approaches the worn-out phase, the release load starts to go up. This is an indication of the system reaching the end of its service life prior to finally wearing out and slipping. An unnerving byproduct of this increasing release load of a worn out system is that when the new system is installed, the pedal effort is back to its original values and the clutch pedal feels too soft. An exception to this is the new clutch cover used with the G56 that uses a Self Adjusting Clutch (SAC) made by LuK which maintains the release load throughout the service life of the system.

Plate lift is the distance that the pressure plate moves away from the disc to let the disc spin down and allow for gear changes. The pressure plate in this test started moving at .300" bearing travel. At almost .550" bearing travel the plate has lifted by .040" and the lift is parallel within .005". We want to see a nice parallel plate lift, not one side dragging and not lifting. On our Dodge clutch covers the plate lift is controlled by the drive straps. As you push down on the clutch throw-out bearing, the diaphragm spring pivots in the housing and the spring lifts off of the casting, removing the clamp load, and the spring steel drive straps start pulling the casting away from the disc. Take a close look at your next clutch; all of the power produced by that massive Cummins goes through those four sets of spring steel drive straps as they pull the casting in rotation with the housing.



## Clutch Discs.

Clutch discs. Ah ha! The voodoo magic of a clutch system, the material composition of the clutch facing. Much like the composition of brake pad material (that voodoo science was discussed by TDR's brake guru, James Walker, back in issue 41), the clutch disc material can be made from a variety of different materials. But each material is a compromise; Let's take a look.

### Organic Facings

This class of friction material is the original equipment type installed when our trucks were built. It is a fiberglass based product that uses a woven fiberglass that has been treated with various resins and chemicals. This yarn is then woven into a blank that is then pressed, baked, ground and drilled into a modern facing. These facings have good smooth engagement qualities and a long service life. The drawback for this facing type is that their coefficient of friction is lower than other materials. **(Coefficient of Friction-** A dimensionless number, proportional to the ability of two surfaces in contact to resist slippage.<sup>1</sup>) The higher the coefficient of friction, the higher the torque capacity of the clutch system and its resistance to slippage.

### Cerametallic and Ceramic Facings

**Cerametallic Facing-** A facing which is a combination of ceramic and metallic compounds. **Ceramic Facing-** A facing composed of heat resistant and corrosion-resistant materials. These are optional facings, they have not been offered as original equipment on our trucks. These have a higher coefficient of friction and have been the primary facing of the over the highway "Semis." They can last for a long time and provide severe-duty service. If you install one of these discs, you will notice that they engage quicker. I advise customers to use first gear and just smoothly and with a continuous motion engage the clutch; you'll find these are quite streetable once you learn how to use them.

### Kevlar

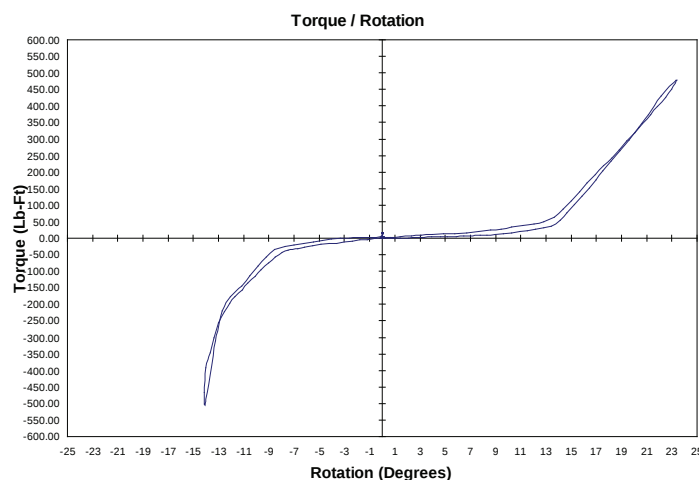
Kevlar has also been used as a friction material. It has a higher coefficient of friction than organics, smooth engagement and a high resistance to wear.

Which facing is right for you? Depending on your truck's power level, how you use the truck and your future plans, the selection of the correct friction material is critical to your truck's clutch.

## Torsion Dampers

The job of a torsion damper might best be described as a filter between the output of the engine and the input to the transmission. If the rotational output of any reciprocating engine were absolutely constant, we wouldn't need torsion dampers (the fancy springs in the center of a clutch disc) in clutch discs. But, what the crankshaft delivers to the flywheel is a series of power pulses. If you pass those pulses directly to the transmission, you can expect gear noise at certain power levels. This is most obvious at the drive-in window or toll booths when you put the transmission in neutral and engage the clutch. Yep, that rattle you hear is transmission gear noise. Clutch manufacturers use a series of coil springs to buffer or dampen the spikes into a smoother power output to the transmission. Torsion dampers have been built in a lot of design types and configurations. In the First Generation trucks, the disc is a very basic strong damper with a small external pre-damper. Just a comment on this system: it was actually derived from existing designs used in Germany and Brazil for Mercedes-Benz mid-range trucks. The NV4500 and NV5600 use a large damper with predampers to deal with the gear noise that can be created at idle. It is pretty effective and does a great job within its suitable power range. With the new G56, Dodge is using a Dual Mass Flywheel and torsion damped disc for this powertrain.

When we test a torsion damper it requires that we clamp the disc in a fixture so it does not rotate, then twist the input shaft and plot the degrees of rotation traveled vs. the torque required to rotate the input shaft in both drive and coast. The test helps define the damper function.



|                |            |                     |    |
|----------------|------------|---------------------|----|
| Perf #         | D1935      | Machine CCW Degrees | 23 |
| Manufacturer   | LuK        | Machine CW Degrees  | 14 |
| Manufacturer # | 52107775AC | # of Splines        |    |

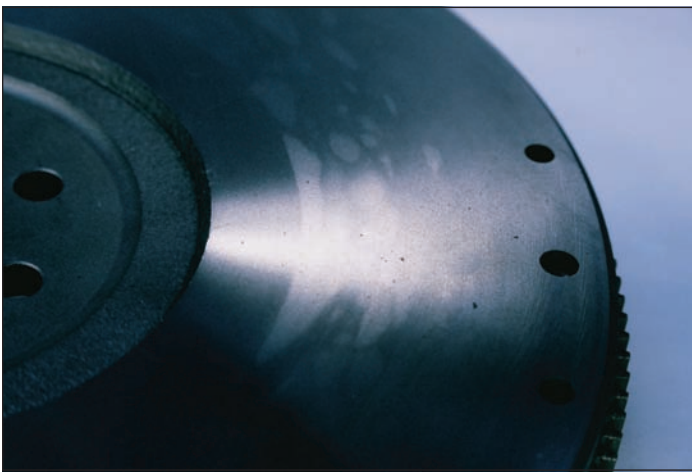
## Common Installation Oversights

The TDR has had many excellent articles written on clutch installations. As the Director of Training for Perfection Clutch/ ZOOM Clutch, I want to offer some do's and don'ts from our point of view for a clutch installation. For starters it is very important to inspect the old system. In almost all cases the parts are telling a story. It's investigation time.

- Flywheels. These need to be replaced or professionally resurfaced. Even with resurfaced flywheels the internal hot spots are not always removed and the overheated hot spot areas actually become high spots and can cause chatter with your new clutch.



Shown is a used flywheel that needs resurfacing or replacement.



The resurfaced flywheel.

- Clean the friction surface of the flywheel and clutch casting surface with a brake cleaner product or alcohol. Do not use solvent from the parts tank.

- Thoroughly clean the input shaft and get all of the old grime and rust off of the splines. You can apply a small amount of high temperature wheel bearing grease to the splines. The grease helps prevent corrosion and keeps the disc sliding on the shaft during release. Do not use anti-seize.



Time to clean up this input shaft.

- Do not contaminate the friction material. These discs are a dry friction material and any contamination can cause chatter or slippage.
- Use the alignment tool to center the disc on the flywheel. Handle the transmission with finesse and carefully guide it into place. If the transmission is allowed to hang on the disc, the damper and disc try to hold the entire weight of the transmission, resulting in a fractured disc or damper. I have found that if you rotate the output shaft while you are installing the transmission it helps align the input shaft and allows it to slide in smoothly.
- Tighten the clutch cover bolts in a criss-cross pattern about  $\frac{1}{2}$  turn at a time. Do not get the impact and set it on full stun and double tap them in. Doing this results in irregular spring tip heights and chatter or even release problems.
- Check the details of the release system. Check pivots, forks, guide tubes; clean the parts and lubricate the pivots. On our Dodges take a close look at the fork: it can go in on either orientation, but only one is correct.
- Dowel sleeves. These are in the adapter housing and they precisely locate the position of the transmission to the engine, basically creating concentric alignment of the crankshaft to the input shaft. Let me emphasize, these are critical to the long life and proper operation of the system.
- Attention to detail: This is one of the most important tools in our toolbox.

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### Driving Tips to Extend the Service Life

- Do not rest your foot on the clutch pedal. Any force applied to the pedal is multiplied by the hydraulic system and the mechanical advantage in the pedal and lever ratios. This creates an increase in the designed release bearing preload and shortens the life of the clutch system. Our trucks do not have free play. The bearing is turning continuously.
- Engage the clutch at the engine idle speed and let the mule dig in and start pulling. If you engage at higher engine RPM, then you are creating extra slip time and the resulting heat must be dissipated, again resulting in reduced system life.
- Use first gear. Minimize the slip time to equal longer system and disc life.
- Do not lug the engine. Downshift and let the transmission do its share of the work.
- Do not use the clutch as a hill holder. Use the brakes.
- I personally select neutral at lights just to minimize the loaded time on the release bearing and the spin time of the pilot bearing.

### Performance Upgrades

In order to help you understand your clutch better and evaluate the available system upgrades, you'll need to know the engine's torque and the capacity of your clutch system.

For this I refer to the S.A.E. Manual Transmission Clutch Systems, publication AE-17 Clutch Handbook as a guide. The formula in this book multiplies the clampload, radius, friction surfaces and coefficient of friction of the clutch facing. To increase the torque capacity of a system, one or more of the above factors must be increased, like higher clamploads and/or a higher coefficient of friction. These are the most commonly modified values. Designing a clutch system for big power is not as complicated as it seems. Just realize that there are compromises that will have to be made to have the clutch system transmit the higher torque of the engine.

Call a clutch professional!

**Gary Croyle**  
**Perfection Clutch**  
**Timmonsville, SC**

# Coolant

ISSUE 62

## ANTIFREEZE FOR YOUR TRUCK

by Robert Patton

In this issue we're going to cover another subject that causes confusion among the TDR faithful (although nowhere near the emotional reaction as our recent lube oil articles in Issues 54-58): the correct antifreeze for your truck. Issue 54's article by Andy Redmond gave you the Chrysler and ASTM specifications that you should use in your purchase decision. Yet, with the wide choice of products at the auto parts store, it puzzles the mind. How so?

In looking for a way to introduce the subject there were many titles that were considered: the straightforward, "Read Your Owner's Manual"; the condescending, "Your Perception is Reality"; the jovial, "Antifreeze and You"; the serious, "The Need for Coolant Additives"; the interactive, "A Coolant/Antifreeze Pop Quiz"; and the technical, "Specification Numbers and Antifreeze."

The decision—let's do, "13 Questions About Your Cooling System." The article covers more than just antifreeze, so read on.

**Q1** *I've often heard the term "cavitation erosion" in the same sentence as diesel engine. What is cavitation erosion?*

**A1** With a term like "cavitation erosion," you might think those affected would be found in the waiting room at your dentist's office. Not so. Cavitation erosion or liner pitting, if left unchecked, is a real issue with *some* diesel engines. Okay, I guess there is a parallel to your dental hygiene. A cavity is a cavity, and both types can drain money from your wallet.

To further clarify the issue, you may have noted that the cavitation erosion is an issue with *some* diesel engines. Which ones? All diesel engines with *wet* sleeves are subject to cavitation erosion or liner pitting if the cooling system is not properly maintained. The wet-sleeve design means the cylinder liner can be removed and replaced in the block. Although the cylinder liners are pressed into the block, wet cylinder liner design does not have the same structural rigidity as a cast block design. Under-concentration of coolant treatment additives will result in liner pitting and engine failure.

The Cummins B5.9 and 6.7 liter engines are a cast block design and do not have wet or removable sleeves.

To add further explanation to the liner pitting phenomenon, I'll quote from a Cummins Inc. Cooling System brochure. "Liner pitting is caused by vapor bubbles formed when the piston strikes the liner during engine operation. The energy generated during the combustion process and the side-to-side motion of the piston causes the liner to vibrate at a very high frequency. The liner moves away from the coolant fast enough to form vapor bubbles.

"The vapor bubbles collapse against the liner surface as the liner moves back into the coolant. The implosion of the vapor bubble against the liner surface produces a very high velocity jet of water. This water jet removes material from the liner surface. The jet of water acts on the liner surface with a pressure exceeding 15,000 psi. This process repeats again and again, resulting in liner pitting."

**Q2** *Is cavitation erosion or liner pitting a concern on my Turbo Diesel?*

**A2** No. Again, the Cummins B5.9 and 6.7 liter engines are a cast block design and liner pitting is not a concern.

**Q3** *How about my buddies with their Ford and GM diesels? Aren't both of those engines cast block designs?*

**A3** Yes, they are. My friends with the GM engine advise that their Owner's Manual does not mention the need to treat the cooling system with supplemental coolant additives (SCA). However, even though the Ford is a cast block design, the PowerStroke owners *must* use SCAs to prevent the cavitation erosion problem.

**Q4** *Okay, I understand that the Cummins B5.9 and 6.7 liter engines do not need supplemental coolant additives. But, I would like to learn more about SCAs so that I can inform some of my Ford friends. Tell me more about SCAs...*

**A4** How about an easy-to-understand analogy?

Do you wax your vehicles? Just like waxing is necessary for long lasting paint protection, SCAs form a protective coating on the engine's cylinder liners. Just like wax wears away, the SCAs have to be replenished in the engine's cooling system. There are easy-to-use test strips (remember high school chemistry?) that tell the owner how often/how much SCA to add to the cooling system.

**Q5** *In issue 54 TDR writer Andy Redmond gave us the specifications for coolant. Could you do a reprint?*

**A5** You bet. Here is the Issue 54, page 157, reprint:

**Coolant Data Chart For '89-'06 Trucks**

| Model Year  | Coolant type                        | Capacity                                                                                             | Normal drain/refill                    | Specs                                                                                                                     |
|-------------|-------------------------------------|------------------------------------------------------------------------------------------------------|----------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| 1989-1993   | Ethylene Glycol                     | 13-16.5 qts.<br>(Check your Owner's Manual.<br>The capacity varies by year<br>and transmission type) | Within 2-3 qts. of<br>system capacity. | (Dyed green)                                                                                                              |
| 1994-1998   | Ethylene Glycol                     | 6.5 gallons (26 qts.)                                                                                | 5-5.5 gallons                          | Low silicate antifreeze per<br>ASTM D-4985/GM6038m<br>ASTM D-3306<br>(Often dyed green)                                   |
| 1998.5-2002 | Ethylene Glycol                     | 6 gallons (24 qts.)                                                                                  | 5-5.5 gallons                          | Low silicate antifreeze per<br>ASTM D-4985/GM 6038m<br>ASTM D-3306<br>(Often dyed green)                                  |
| 2003-2008*  | Ethylene Glycol<br>HOAT formulation | 7.3 gallons (29.5 qts.)                                                                              | 6.5 gallons                            | Mopar 5 year/100,000 mile life<br>with HOAT (Hybrid Organic<br>Additive Technology). MS-9769<br>(pink to orange in color) |

\*Some Turbo Diesels come from the factory with the green dyed ethylene glycol versus the orange "HOAT" coolant (2003-2005).

**Q6** Since 1989 the coolant type listed is ethylene glycol. How does ethylene glycol (EG) compare with propylene glycol (PG)?

**A6** Ethylene glycol and propylene glycol are clear liquids used in antifreeze and deicing solutions. Both are clear, colorless, slightly syrupy liquids at room temperature. Ethylene glycol is odorless, but has a sweet taste. Propylene glycol is practically odorless and tasteless.

Ethylene glycol is toxic. Eating or drinking ethylene glycol can result in death, while small amounts can result in nausea, convulsions, slurred speech, disorientation, and heart and kidney problems.

Ethylene glycol affects the body's chemistry by increasing the amount of acid, resulting in metabolic problems. Similar to ethylene glycol, propylene glycol increases the amount of acid in the body. However, larger amounts of propylene glycol are needed to cause this effect.<sup>1</sup>

**Q7** It seems that PG would be, literally, a safer product to use. Why is it not widely accepted?

**A7** Ethylene glycol (EG) has been in use since the 50s. The propylene glycol (PG) solutions were introduced in the early 70s. They were initially marketed as non-toxic. There was an industry uproar and court action forced the manufacturers of propylene-based antifreezes to relabel their products as low-toxicity.

In my discussions with Dave Embaugh at Valvoline/Zerex, I asked questions about these two glycol coolants. There is a 20-25% price premium for the propylene-based coolants. With the price premium for PG, it is a given that all new vehicles come from the factory with the less expensive ethylene glycol-based antifreeze. In the aftermarket, the EG fluids have a market share of 95%; the PG fluids have the remaining 5%. Embaugh notes that the two types of coolants should not be mixed. PG maker Sierra Antifreeze's web site recommends a cooling system flush before switching to their product.

**Q8** Okay, the Chrysler's recommendation up to year 2002 says ethylene glycol. Isn't that the traditional "green stuff" that has been around for years?

**A8** Yes, just be sure to use a low-silicate antifreeze per ASTM D-4985/GM6038M and ASTM D-3306.

**Q9** Why all of the fuss over low silicates?

**A9** The good old green stuff is known as inorganic additive technology (IAT). The IAT coolants have been around for generations. They contain silicates that form a protective barrier on everything in the cooling system, even rubber hoses.

Silicates plate-out quickly on metal engine parts; thus the silicates in a coolant solution can drop to less than 20 percent of the starting level in less than 10,000 miles. Another problem with silicates is that, under certain conditions, they can drop out of the solution and form minute deposits.

If this occurs between the shaft and seal of your water pump, the resulting abrasion will eventually cause a leak. In a cooling system that turns off coolant flow to the heater core when the heater is not in use, silicates can form a gummy deposit that, over the course of a summer season, might clog the core tubes.

So why even use silicates? Because they're really good at what they do, especially in iron block/aluminum head engines. That's why some manufacturers still specify using coolants with silicate corrosion inhibitors.<sup>2</sup>

**Q10** *So I understand that the green stuff (an ethylene glycol, EG, IAT, silicate formula) antifreezes need more frequent servicing as they plate-out as they provide a protective barrier to corrosion. How about Chrysler's recommendation for the '03-'08 cooling systems of a hybrid organic additive technology (HOAT) that is good for 5 years/100,000 miles? What is HOAT?*

**A10** While there are some minor variations, there are three basic types of coolant available today: inorganic additive technology (IAT – typically dyed green), organic additive technology (OAT – typically dyed orange), and hybrid organic additive technology (HOAT – typically dyed yellow). To some extent, each will work in any cooling system, but each has been developed to meet car manufacturers' specific needs for warranty and/or maintenance intervals. Filling a vehicle that was designed for one type of coolant with another type can sometimes cause problems, and if you mix-and-match coolants the same corrosion protection as the initial factory fill shouldn't be expected.<sup>2</sup>

To understand Chrysler's recommendation of *hybrid* organic additive technology (HOAT), one must first understand the silicate-free OAT antifreeze. The newer OAT coolants work differently than the older silicate, ethylene glycol, IAT coolants (the green stuff). Aluminum and ferrous metals form a surface-layer of corrosion in the presence of moisture, even the little bit of moisture in the air. OAT coolants anneal this metal-oxide layer into a thin surface coating that protects against further corrosion. Inherent with their design, the OAT coolants last longer than the old green-stuff IAT coolants. Regardless, with either type of inhibitor, there must be enough in the coolant solution to occasionally re-establish the barrier as needed.

It took almost 20 years of OAT development to make a coolant that would effectively protect against corrosion without using silicates at all.

As a bridge between OAT and IAT there are the hybrid coolants (HOAT) that use both silicate and organic acid corrosion inhibitors. HOAT type coolants are the factory fill for many OEM vehicles.<sup>2</sup> Your '03-'08 Turbo Diesel uses HOAT.

**Q11** *How much of the coolant is actually additives?*

**A11** With all of the discussion about IAT, OAT and HOAT, you'll be surprised to know that the corrosion protection percentage of the mixture (matters not if it is EG or PG) is usually less than 4%, meaning the true "antifreeze" or glycol portion is 96%.

**Q12** *Is there a one-size-fits all coolant?*

**A12** To quote Dr. Paul Fritz, senior coolants technologist for ChevronTexaco Products Co., "Nothing bad will happen" when two brand-name coolants with different corrosion inhibitor technologies are mixed. By this he means that no sludge will form, there will be no damaging chemical reactions and the coolant will still carry heat and protect against freezing.

However, when adding an IAT to an OAT system, the recommended coolant change interval will degrade to that of the shorter-life coolant. Typically, when the mixture stays below 25 percent new coolant on top of 75 percent of the original coolant, the corrosion protection performance will remain that of the original coolant. But as the mix of coolant technologies deepens—that is, if a cooling system has a slow leak and it's continually topped off with a type of coolant that's different from what is already in there—eventually the original corrosion inhibitor will be replaced by the new corrosion inhibitor. This will determine the resulting mixture's overall performance. If someone continues to top off a five-year coolant with a two-year coolant, the resulting coolant mixture should now be changed every two years.

But you should not mix-and-match. According to Dr. David Turcotte of Valvoline Co., cooling systems are mechanically designed to work with specific types of coolant.

Filling a system with the wrong coolant could cause problems. In a 300-hour test of OAT coolant in a Ford engine designed for HOAT coolant, the water pump impeller and backing plate were seriously damaged by cavitation corrosion.

Turcotte and Fritz both said that it's not possible to have one product that meets the coolant requirements of all the different automakers. Because some OEMs require silicate-free coolant and others mandate the presence of silicate, "one size does not fit all."<sup>2</sup>

**Q13** *What coolant should I use?*

**A13** Looks like we've done a complete 360° walk around the block (cylinder block, that is). Please see the reprinted table that Andy Redmond provided in Issue 54. The short answer: Chrysler specification MSS-9769, HOAT coolant which is backward compatible to all years of the Turbo Diesel. That's right, use the yellow stuff after you drain the green stuff. And, thankfully we do not have to be concerned with cavitation erosion.

**Robert Patton**  
**TDR Staff**

<sup>1</sup> Agency for Toxic Substances and Disease Registry web site [www.atsdr.cdc.gov/toxfaqs/tf.asp?id=85&tid=21](http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=85&tid=21)

<sup>2</sup> Aftermarket Business, May 2005, Author Jacques Gordon

# My Truck Won't Start

ISSUE 81

## MY TRUCK WON'T START

Introduction by Robert Patton

As I listened to one of the Geno's Garage staff members walk an owner through what to do, it happened that the country music song "You Never Even Called Me By My Name" by David Allen Coe was playing in the background. Coincidentally, lyrics in this song that talk about "the perfect country and western song" gave me inspiration to write an article on fuel transfer pumps that is archived in the [Turbo Diesel Buyer's Guide](#), pages 266-285. Should it be considered "perfect?"

Likewise, I asked TDR writer Joe Donnelly to do a Perfect-type article on HPCR injectors. That article was an update of his text from a long ago story and it is found in Issue 72, pages 44-54. Looking closer, writer David Magnoli did a Perfect article on exhaust brakes; see TDR 71, pages 48-52.

Then there is the lube oil Perfect story: Issue 76, pages 52-57.

Then there is the suspension woes Perfect story: [TDBG](#), pages 255-265.

Then there is the harmonic balancer Perfect story: Issue 73, pages 44-51.

Then there is the low pressure fuel system Perfect story: [TDBG](#), pages 291-294.

Then there is the emissions legislation Perfect story: [TDBG](#), pages 90-95 and 129-134.

But, I digress.

Is it time for the Perfect "My Truck Won't Start" story? Perhaps it is.

Now, before I reinvent the wheel, I went back to previous TDR magazines to see if there was an article that I could use as a springboard for the Perfect won't start story. Just like the Joe Donnelly perfect-injector article, I found that writer Andy Redmond gave us the basics in his Issue 73 report. Logically, I called Andy and asked him to update/add to his story. Andy files the following report.

## NO START – UPDATE 2013

By Andy Redmond

The best way to start this update is to look back to my previous articles, proofread them for clarity, and add new information. Previously I had laid-out the tips in an order that corresponded to the vintage and year models of the engine. I'll continue to use this format:

'89-'93 First Generation

'94-'98 12-Valve

'98.5-'02 24-Valve

'03-'07 5.9 HPCR

'07.5-current 6.7 HPCR

Although as a general rule I hate to repeat previous articles, the editor and I agree that the previous text (Issues 73 and 75) was spot-on. Here goes with the report and updates.

### The Basics

One of the more frequent complaints that come across my desk is, "My truck won't start." So okay, but I need something more specific. Will the engine crank over but not start, or is there just nothing? A little information on the basics goes a long way in helping me be helpful.

Before I present my no-start tips and suggestions of things to check, I must be sure you understand the basics—there has to be fuel delivery by the truck's low-pressure fuel delivery transfer pump. This fraught topic has been covered so many times that the TDR writers simply say, "TDBG [Turbo Diesel Buyers Guide], pages 266-284 and 291-294"; or "Issue 56, pages 60-75 for the transfer pumps." Rapid-fire references, we've all been there and done that. So, how is that for covering much matter in few words?

Since we have mentioned fuel transfer, we should note a common diesel-beginner's problem before I get to a survey of respectable no-start problems. Let's deal with this preliminary complaint first: "I just changed the fuel filter (but I didn't bleed air out of the system) and now it will not start." If you make this diesel-rookie mistake you'll want to stop cranking, re-prime the fuel injection pump by using the push lever transfer pump (in 12-valve engines) or cycling the key on to bump the starter, release and listen for the transfer pump to operate ('98.5-'09 engines with electronic transfer pumps). With a complete re-prime let's hope the engine cranks. If it doesn't start, you are faced with a dilemma: do you break loose the lines to the injectors ('89- '02 engines) and bleed air out of the system? On the newer '03-current engines the fuel system will self-bleed, so if you are faced with a long crank time on this vintage engine, you'll be looking for a swift kick to re-energize the batteries.

On a side note, the editor (in typical Bubba-knows-best fashion) would suggest that you disconnect power to the air intake grid heater units (in weather below 60°) and coax the engine to stumble and run on ether.

My opinion on ether differs.

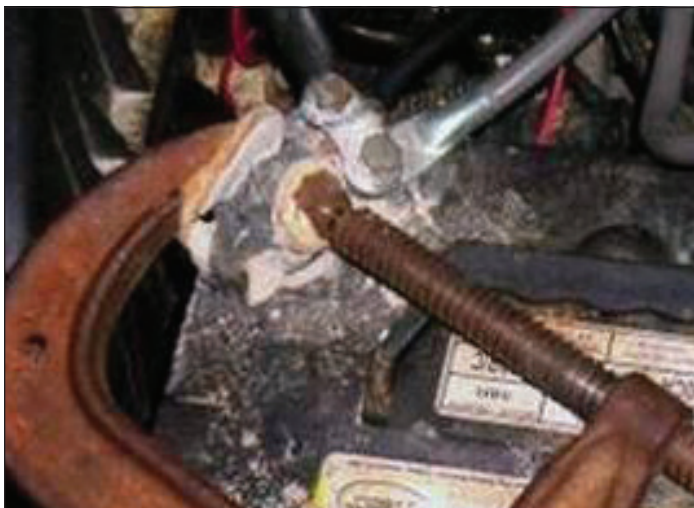
Ether has been discouraged for use in modern diesels. Ether is bad for engines and fuel systems. Even back in the early 24-valve days, a tired truck that got an ether shot for “priming” would sometimes gaul/seize the pintles inside the nozzles—causing the demise of already tired injectors. We know common rail equipped engines can barely tolerate clean diesel, much less running without its lubricating properties.

In the hands of the inexperienced (those that push the envelope of “a little bit”), internal engine component damage has been observed—cracked pistons, holes in pistons, etc.

If you must use an alternative fuel for priming (after disabling air intake heaters)—use something less volatile like WD-40, silicone spray, 90/10 mixture of diesel/gas in a squeeze bottle (think science lab bottle, with pinpoint nozzle). This method is most effective while an assistant cranks over the engine, while a short squirt added to the turbo inlet. Hmmm...“I am my own warranty station” comes to mind. Again, I would *not* suggest the ether technique.

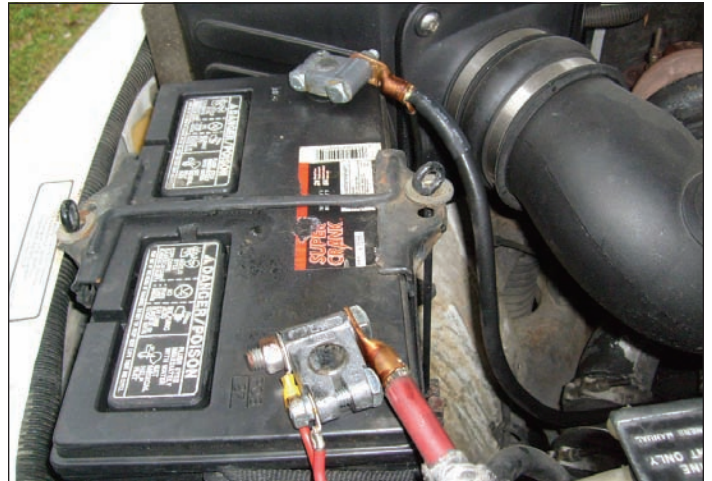
### Common Problem – Batteries

With the key in the start position a failure to hear your starter motor turning/engine cranking should cause you to examine your batteries. Oh great, here we go down the batteries maintenance memory lane again, you say? They do wear out you know! If time for replacement, avoid the chain auto part stores or big box retailers—you will get what you pay for! Battery performance is directly commensurate with the circuit and terminal connections attached to it! This segues nicely to the photo in Issue 74, on page 36.



It is easy to discern the difference between Freddy Frugal and Foolish Freddy! If your batteries look like this this, they are due for replacement due to the acid's out-gassing alone. The

photo shows a necessary multi-step repair process beyond the installation of two new batteries. Certainly the battery terminals, and very possibly the battery cables, will also require replacement. This TDR member can only hope that the acid corrosion hasn't migrated down the copper strands under the cable's insulation, damaging the cable. The battery terminals you want are not the cheap “auto parts special” variant. Issue 74, page 32, depicts a proper terminal repair.



Except for the '89-'93 trucks, all other Turbo Diesels utilize two batteries wired in parallel. These should always be replaced in pairs, as replacing just one will quickly destroy the new one. It is also smart to isolate each battery for testing (load, open circuit voltage, etc.).

So, when there is “just nothing” and, perhaps, a click-click noise, you should focus your attention to the batteries, battery terminals, or a defective (worn out) starter.

On the earlier '89-'98, mechanically injected, 12-valve engines, a low voltage problem can allow the fuel shut down solenoid either to not open or not open fully, either of which can hinder fuel flow to the injection system. In the case of the '98.5-'02 years, the engine control module (ECM) can reset as the battery system voltage drops below 9.8 volts. Similarly on the HPCR trucks from '03-current the ECM can reset and prevent injector solenoid actuation. (A common example being trouble code P2509: ECM power signal intermittent/powerdown data loss.) Details on these problems are found further into the article.

### Common Problem – Starter

What is the common cure for the dreaded click-click and the starter motor not turning? Replacement of the starter contacts in the starter solenoid are most often the cure. Many vendor kits include a new solenoid plunger and upgraded battery and starter motor contacts. Although a simple repair, the biggest challenge faced by the D-I-Yer is that of removing the starter.

**Editor's note:** *Don't always assume the click-click is worn starter contacts. First make sure the batteries are up to the task of powering the solenoid and starter. If the batteries are good, you can then focus your attention on the click-click noise being caused by the worn contacts in the starter's solenoid.*

To start the project, Freddy Frugal's toolbox should contain a sturdy 12 point, 10mm box combination wrench. No doubt as you attempt to remove the starter you'll wonder, "Who is that gorilla on the Cummins engine assembly line that torques those three starter bolts?" Removal tip: Position the box combination wrench on a starter bolt and use a 2x4 block and a bottle jack as a fulcrum to loosen the bolt(s). The battery grounds should be removed from each battery. Next, the starter solenoid trigger wire nut is removed (8mm) as well as the nut (usually 17mm) which retains the starter motor battery wire.

Once the starter is on your bench, the solenoid cover can be removed to reveal the plunger and contacts. The plunger is spring loaded, so be sure to note assembly orientation. Also use caution not to lose the "bb" ball bearing down at the base of the solenoid's spring cavity. Likewise, it is important to keep the new contacts flat on the solenoid base, because they will tend to rotate as the contact bolts/nuts are tightened.

While we are on the subject of starters, a TSB covers the 2000 models that might blow fuse D, a 20 amp fuse in the underhood power distribution center. TSB 08-01-00 Revision A advises a larger replacement fuse (25amp) after the installation of an overlay harness Mopar 05019015AA.

Now, back to the main subject: no-start tips.

### **1989-1993 First Generation — Cranks, But No Start Most Common Problem(s)**

Even though fewer of these are on the road these days, a loyal following still exists. The Cummins engine runs a long, long time. A no-start alarm came recently from a member in New Hampshire, who had determined that the engine cranked in fine fashion, but noted that no fuel was present at the injectors. He had replaced the diaphragm style lift pump due to insufficient fuel pressure and volume. Also prior to calling, he tested the fuel shutdown solenoid that threads into the top rear portion of the Bosch VE pump. He reported noting proper system voltage (even during engine cranking) and a good reading in the ohm test (7 ohms, with power lead disconnected).

I suggested that he remove the solenoid, removing both the plunger and spring, then reinstall the solenoid minus these parts. I pointed out that it would be necessary to manually hold the shutdown lever down to shut the engine off should it start using the modified solenoid. Several injector nuts were loosened to allow the air to purge. About two minutes later he called to inform me that it started right up and ran fine. Although the solenoid had tested okay a new shutdown solenoid solved his problem. He was even elated to find a bargain at an online retailer mentioned in prior issues. ([www.hansautoparts.com](http://www.hansautoparts.com)). Fourteen dollars later a part arrived at his door. Should you need this part locally from a fuel injection pump shop, I've found this Zexel (a Bosch company) part number (146650-0720) to work well. (See Issue 62, page 112, for additional information on the Bosch VE Pump, "Modifications and Troubleshooting.")

### **1994-1998 12-Valve - Cranks, But No Start Most Common Problem(s)**

The standard troubleshooting routine applies to the 1994-1998 12-valve Turbo Diesels, although they use an external solenoid and linkage to operate the start/stop lever on the Bosch P7100 injection pump. These trucks also have a problematic solenoid relay (located above fuel filter and attached to the firewall.)

The following are some tips for troubleshooting the most common '94-'98 12-valve no-start situation:

Should the fuel start/run solenoid fail to energize (come up) and hold in the "up" position, do not let its malfunction leave you stranded. Have an assistant attempt to start your truck while you move the solenoid's plunger up to the "run" position. If it starts and the solenoid holds in the "run" position, drive it to your destination for further troubleshooting as time permits. If the solenoid fails to hold in the "run" position, tie-wrap it in the "run" position, and drive it to your destination. Cut the wrap, and the engine will stop.

So, this tip would get you to your destination. But the problem is still unsolved: Does it lie with the solenoid, the relay to the solenoid, the fuseable link that feeds the solenoid, or a fuse?

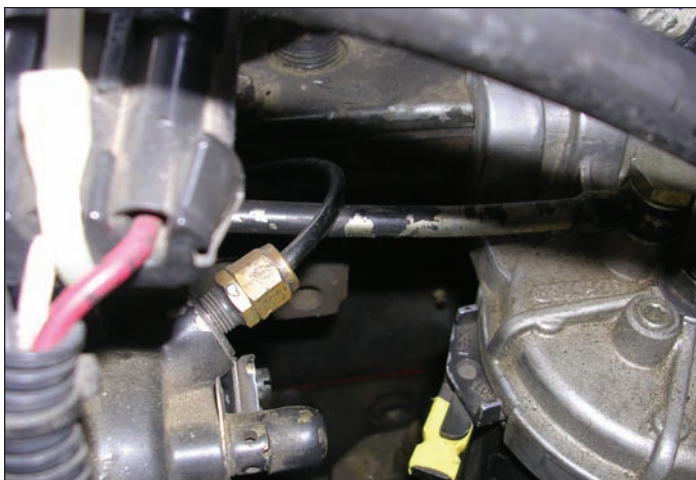
Do a voltage check at the solenoid's three-wire connector. Negative goes to the Black/Red trace wire. On "start": positive 12-volts will be at the Red/Black trace wire. If voltage is present for "start," the solenoid is likely the problem. No voltage for "start"? Chances are that the solenoid is okay. Check the relay, the fuseable link or fuse #9 as the source of the electrical malfunction.

Another common problem with the '94-'98 12-valve engine is an old, cracked or leaking fuel return hose. I went way back to Issue 23 to find a write-up on this pesky problem. Here is the report:

Hard starting after overnight sitting? If so, it is likely the drain back hose at the rear of the injection pump on the '94 to '98 P7100 fuel pump. This topic has been covered several times in the TDR and as an independent service shop I would like to reiterate the problem/solution.

It seems that the hoses were painted on the assembly line and therefore they cannot breathe, which causes them to rot, leak and lose the fuel prime, resulting in hard starting the first thing in the morning.

It is hard to find if you don't know where to look. When you go back to the dealer, you can inform them what is causing this problem. It is a 5/16 hose, 18 inches long. The fuel line should meet the 30R7 rubber specification.



The suspect hose for fuel return is in a hard-to-reach area. Note the threaded hole in the block in each photo for location.



Since this hose is so hard to see, it often gets overlooked while troubleshooting a no-start situation.

### All 12-Valve Engines ('89-'98), Long Story

From this subtitle you can see that I am trying to write the Perfect won't start story. In order to perfect the Perfect, here is a thorough article that was written by the TDR's Jim Anderson way back in Issue 22. Jim Anderson files the following report for '89-'98 12-valve no-start troubleshooting. I'll start writing again on page 120, "'98.5-'02 24-Valve – Cranks, But No Start."

Recently, it occurred to me that a full article outlining hard start/no start problems, and their possible causes might be in order. Putting it in a form you can copy and put in the glove box for emergency use might be very helpful when your super-faithful Cummins fails to fire on the first round as it has always done before. No-start conditions only occur in large parking lots at night in the rain, or a zillion miles from nowhere under similar weather conditions—never at home in the garage (well... almost never). That's Mr. Murphy's law. But, it can happen anytime because even dependable parts can fail.

I was so surprised the first time this hard starting happened to me, I couldn't believe it, and simply sat in the driver's seat dumbfounded

(a normal personal condition according to my wife) for several seconds, then tried to start the engine again with the same result. I just couldn't believe it! I had good starter operation, the engine spun fast enough to run, but it didn't fire and no smoke came from the tailpipe. Therefore, I determined no fuel was getting to the cylinders. The following is how I diagnosed the problem and got it going again.

But first, let's briefly describe your diesel's fuel system operation. It can be divided into three circuits. The first is the low-pressure transport system, which moves fuel from the supply tank, through the transfer pump and fuel filter to the fuel injection pump. Second, the fuel injection pump builds the fuel to high pressure and injects it through the fuel injection lines to the fuel injectors in the engine cylinders at the precise time needed for the engine to fire. The third circuit returns any excess fuel not used in the injection process to the supply tank for re-use. Liquid is non-compressible and air is compressible, so no air can be in the system if it is to work properly. Periodic inspection of all fuel lines, fittings, and piping for wet spots is a good idea, as wet spots indicate fuel leaks and places for air to enter the system.

We'll not attempt with this article to deal with major problems such as broken fuel injection pump drive shafts, low starter speed due to bad or low batteries, or plugged fuel filters or lines, which can be cured best in a repair shop after a tow. Instead, we'll deal with the most likely possible causes and the type of trouble-shooting you can do on the side of the road in a few minutes by yourself, without any tools, with the goal of quickly getting going again if your truck had been previously running just fine. We'll try to refrain from wearing the heady aroma of diesel fuel on our person while doing the diagnostics.

### Heat - Oxygen - Fuel

For the engine to run, it must have heat, oxygen, and fuel. Heat is supplied by the compression stroke of the cylinder firing sequence and is aided by the engine heater grid in the intake system. Unless outside air temp is really low (approximately 40°), the engine should still start without the aid of the engine intake air preheaters, although it will run roughly and smoke until warmed up.

Oxygen – It is unlikely that the intake air system is totally blocked, or it would have been low on power when last operated. Check the air filter restriction indicator to be sure.

There are four pictures with this article to help you identify the mentioned parts. Picture one is of the earlier model ('89 thru '93) fuel transfer pump with lever. Picture two is of the later model ('94 thru early '98) fuel transfer pump with pushbutton. Picture three is of the earlier model fuel shutoff solenoid. Picture four is of the later model fuel shutoff solenoid.

The first item of business is to remember what happened when you tried to start your truck. Did the engine spin at its normal speed? Did it simply fail to start firing? Are you sure there is adequate fuel in the tank? Check to make sure by looking at the gauge, and checking the trip odometer, which you hopefully reset at your last fuel stop.

No fuel, no go, regardless of what the gauge says.

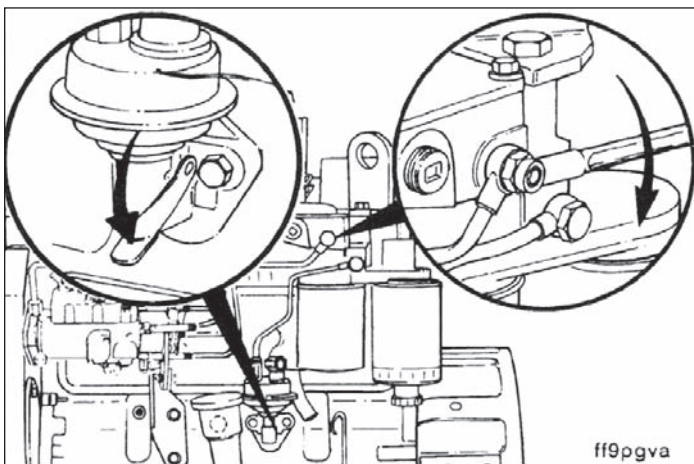
Remember, if you tried to start the engine once and it failed to start, repeated attempts to start the engine without troubleshooting may only compound the problem. Don't crank the engine for extended periods, as this will damage the starter, run down the batteries, and in the case of no fuel in the injection pump, will only admit more air into the fuel system, making it harder to cure your no-start problem.

Briefly operate the fuel drain on the bottom of the fuel filter. Does some fuel come out? Is the ambient temperature cold enough for the fuel to gel (below about 20° without additives)? No fuel at the filter drain and very cold temperatures probably means the fuel has gelled, and the vehicle must be towed to a warm garage to thaw the system and make the paraffin wax go back into suspension in the fuel. If the weather is warmer, then no fuel in the system likely means drain-back of fuel into the supply tank while the vehicle was parked.

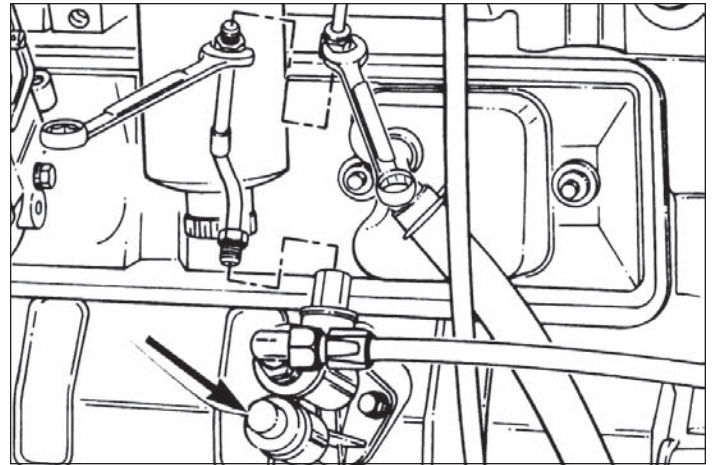
Likewise, if you have a plugged fuel filter, the engine would have had low power during previous use—unless the fuel gelled at low temperature while parked. You might try installing a spare filter, which you *always* carry with you, along with some fuel to fill it before installation. This may solve the problem. Of course, the alternative is to keep it changed on a regular basis to avoid a dirt-plugged filter. If you don't have a spare filter with you, continue to the next step.

That leaves the rest of the fuel system to check.

Fuel-related no-start conditions are caused by a lack of fuel or presence of air in the injection system. Begin your diagnosis by pumping the lever (pre '94 trucks — picture two) or black button ('94-'98 trucks — picture three) on the fuel transfer pump located very low toward the rear on the driver side of the engine. (Find and operate this lever or button before you need to find it in the dark!) You'll find you must push *hard* to make it work! If the system is full of fuel, you should hear a buzzing noise as fuel is bypassed by the injection pump back to the fuel tank. It may take 10-30 strokes on the lever or button to make the overflow bleed buzz if the system lost prime.



1. The location on the engine of the fuel priming pump is the same for all models of the 12-valve engine ('89 thru early '98). This picture shows the "lever" style lift pump used on the pre '94 trucks. (I22, pg21 A)



The location on the engine of the fuel priming pump is the same for all models of the 12-valve engine ('89 thru early '98). This picture shows the "button" style lift pump used on the '94 thru '98 trucks.

Loss of prime can be caused by a leak in the low pressure fuel piping circuits (inspect lines for a wet spot or wear point on the lines), by an air hole in the fuel return line (check for abrasion, heat cracking, of the line), or by a faulty check valve or valves in the fuel transfer pump. The piston type fuel transfer pump (with the black button) has three check valves in it. The lever type pump has two check valves. A check valve allows fuel to go in one direction only. It is open when fuel is flowing toward the engine, and closed when fuel is flowing away from the engine during normal pump operation, thus preventing fuel back flow.

This transfer pump check valve problem happened to me on a trip, and I had to reprime the system every morning for two weeks during the trip until I had time to have the transfer pump replaced. As my truck had less than 100,000 miles on it, this was a warranty replacement item. The pump leaked back little enough fuel that the engine would start after sitting for a few hours, but an overnight stop resulted in a loss of prime, and no start.

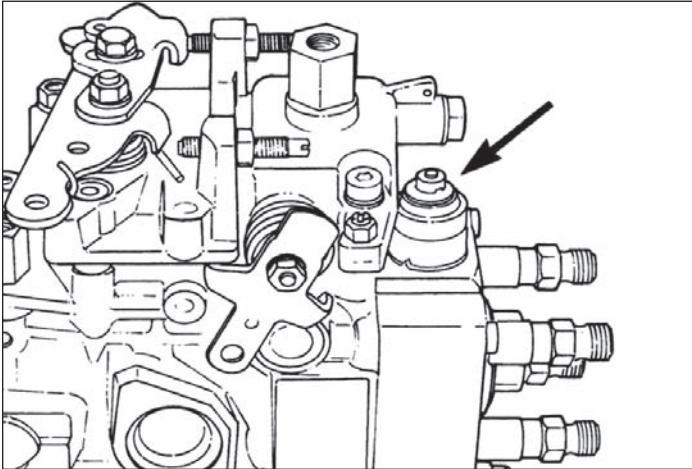
With the system primed, try to start the engine. If it runs, drive on, but have the problem cured at the earliest opportunity!

If the engine still fails to start, check the start/run fuel control solenoid on the fuel injection pump. This was the problem Robert encountered and wrote about in Issue 15, page 69. This solenoid controls fuel supply to the engine. It is energized by 12 volt power from the ignition switch to allow fuel to flow into the injection pump, and is de-energized to stop the flow of fuel to the injection pump when you turn the key off, thereby stopping the flow of fuel to the injection pump.

The solenoid literally runs the engine out of fuel when you turn the key off, as the only way to stop a diesel engine is to shut off the fuel or the intake air, or stall it against a load. A diesel engine has no electrical ignition system. In fact, early diesel truck engines had no shutoff switch, and normal shutoff procedure was to put the truck in gear with the brakes locked and drop the clutch to stall the engine. When you turn the key on, this solenoid should energize by pulling a lever up or otherwise open an internal fuel passage, depending on the model of truck you have. Standing next to the

driver side of the engine with your ear near the solenoid, you should hear an audible "click" when the solenoid is energized by turning the key to the start position. If no audible "click" is heard, there is a fault in the solenoid or wiring, and it must be manually operated to start the engine.

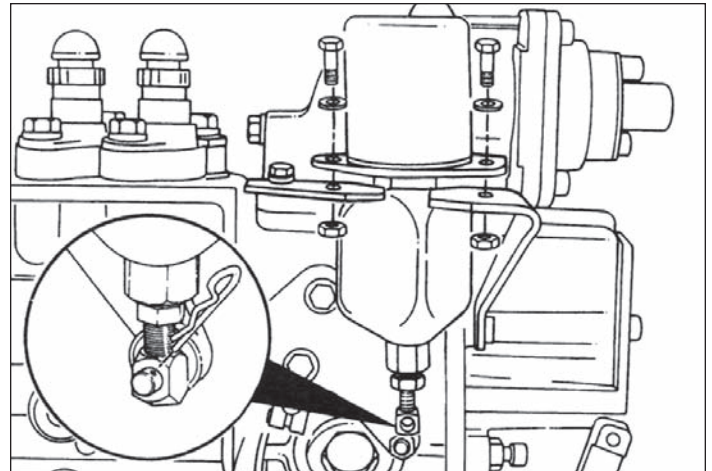
On pre '94 trucks, the fuel injection pump (model VE) is located on the driver side of the engine near the front, and has six lines coming out the pump's rear, arranged in a circle. The solenoid (picture four) is located at the top rear of the injection pump and has one or two wires running to it. When the key is turned on, is there a "click" from the solenoid?



**The Solenoid location on the pre '94 VE style fuel pumps.**

If not, tap several times on the solenoid with a pocketknife or other handy instrument while having an assistant try to start the engine. Hopefully this will dislodge a stuck solenoid and open the fuel passage. If the engine starts, drive away. But don't shut the engine off until you can reach a repair facility, unless you want to go through the procedure again with no guarantee the same trick will work a second time!

On '94-'98 model trucks, the fuel injection pump (model P7100) is located on the driver's side of the engine near the front, and has six lines coming out of the pump's top, arranged in a row. On this model, things are better, as the solenoid (picture five) is located externally to the top rear on the side of the injection pump. It has three wires running to it from a large connector located on top of the engine to the rear of the intake air horn on the driver's side. The solenoid shaft sticks out the bottom of the solenoid and has a small cotter type pin near its end, attaching it to a small lever. With the key "on," rotate the lever to move the solenoid shaft up into its housing, or push the solenoid shaft up and it should hold in that position. If so, start the engine. Drive on, but realize when you shut the engine off, you get to go through the operation again.



**The solenoid on the '94 thru '98 trucks with the P7100 fuel pump.**

Hopefully, the above hints got you going again!

If you have tools with you, and want to get messy with fuel, you might also try bleeding the fuel system at the top of the fuel filter if you suspect air in the fuel system. Open the bleed port with a 10 mm wrench and pump the fuel pump transfer button. If you have a 12-volt test light or volt-ohmmeter with you, you can check the wires at the plug on the solenoid harness for the presence of voltage on the hold-in solenoid coil lead. Other possible causes for a no-start condition could be a plugged fuel strainer (only on some models) in the housing located prior to the fuel transfer pump. This would be a messy operation to clear at the side of the road, and will require tools.

I will again urge you to find the above-discussed items in the convenience of your driveway, before you need to find them in the dark at the side of the road. Both the transfer pump lever or plunger and the fuel control solenoid are hard to see, they are covered by other mechanical bits and pieces, and it will take some feeling around to locate them. But the time spent in locating them before you need them, and observing normal operation, will be invaluable to you at some point in the future! At least you now know more about your Cummins than you did before! Under no circumstances should you try to use "starting ether" or "starting fluid" to "help the engine get running." This will likely cause an explosion in the intake manifold and cause engine damage. (The words "expensive mistake" and "downright dangerous" come to mind!)

If these troubleshooting procedures don't get you started, call a tow truck, as your problem won't be easily solved at the side of the road in your Sunday-best t-shirt, and the additional tests and fixes necessary to solve the problem are beyond the scope of this article. Good luck and I hope it starts for you.

**Jim Anderson**  
Kodak, TN

So, folks, how was Jim's article as a thorough review of the older 12-valve engines and fuel system? In his article I made a few edits, but it has time-tested well. Time to move on to the newer electronic engines.

## 1998.5-2002 24-Valve — Cranks, But No Start

As we move to the newer model years you move away from solenoids and mechanical linkages, to voltage verified at the VP-44 fuel injection pump electrical connector. Here are the simple electrical items to check:

- Check the large connectors mounted to the firewall above/back of the fuel filter housing and make sure the connector is locked.
- Check for terminal corrosion preventing a good electrical circuit.
- Check 6 and 7 at the nine-way amp connector (at VP 44 injection pump module) for 12-volt power (plus, to pin 7; negative, to pin 6)
- If you don't have power at the plug, go to the power distribution center and check the relay (i.e., swap-out with a known good one) that controls the fuel injection system.
- Check the chassis wiring harness for chaffing on the driver's side shock tower.
- Check for a failed lift pump or other lower pressure fuel delivery issues. This is a *huge* issue with the '98.5-'02 24-valve engine with its VP-44 fuel injection pump (read: expensive). The marginal fuel transfer pump that supplies the VP-44 has proven to be very unreliable. Unfortunately, if the unreliable transfer pump does not supply cool fuel to the expensive VP-44 injection pump, the VP-44 overheats, causing excessive internal wear and/or failure of the internal electrical components. More about this in just a moment—for now we are on the subject of the low pressure fuel delivery system.

At the start of this article, I mentioned all of the “perfect” articles that TDR writers have authored. For a comprehensive look at the low pressure fuel system I will refer you back to my article in the TDBG, “Low Pressure Fuel System Problems, pages 291-294”; as well as Writer/Editor Patton's story in the TDBG, “Fuel Transfer Pumps Revisited, pages 266-284.”

How is that for saving paper and ink while ensuring that you have credible data to reference? (Yes, I reread both articles to make sure they were time-tested.)

## Fairly Common Problem – Sensors

Another no start reason might be the lack of a sensor signal to the ECM. Such an example is the crankshaft position sensor. This sensor is located above the vibration damper on the '89-'98 trucks. It was moved behind the starter motor on the '98.5-'00 trucks. The '00-'02 trucks rely solely on the camshaft position sensor for engine position and engine. The '03-current trucks utilize both sensors, the crank sensor being located at the bottom right of the vibration damper and the cam sensor on the back of the gear housing below the CP3/high pressure pump.

I rarely see this problem on the '98.5-'00 trucks. However, when the sensor does fail, it usually illuminates the check engine lamp from

the stored trouble code P0335—crankshaft position circuit high or open. Other signs of a faulty sensor are an erratic, inaccurate or inoperative tachometer.

## Fairly Common Problem – Sensors Again

Another sensor gremlin example: the owner of a '01 truck called when his truck showed a trouble code of P0341: the camshaft position sensor. This sensor is difficult to access, because it is close to the injection pump and vacuum pump/power steering pump. My tool of choice for removing this sensor is a 5mm hex bit in a bit holder and wobble socket extension.

## This is Going to be Expensive...

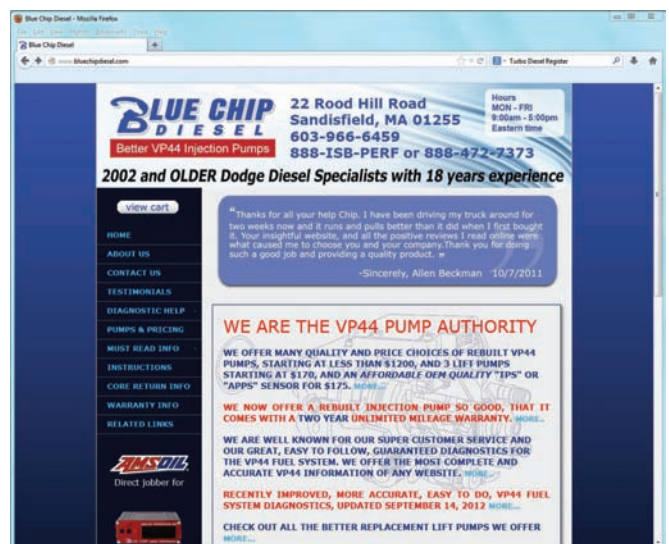
Expensive, what do you mean?

To the point, if your truck will not crank and run because the VP-44 fuel injection pump is bad, a replacement/repaired VP-44 is going to be in the neighborhood of \$1200-2400.

Now, how do you know what is wrong? What are the diagnostic codes? Can you fix it yourself? How do you remove and replace a VP-44?

Much has been written about the VP-44 in the TDR magazine, however, the TDR is not the most authoritative resource for VP-44 troubleshooting. And, while we could plagiarize the hard work of others, change a few words and call the information ours, the editor and I both have a *big* problem with unauthorized reproduction of material. So, let's go directly to one of the best resources that we've found for the VP-44, give credit where credit is due, and work together to help all parties involved.

The resource that we will refer you to for information about the VP-44 is [www.bluechipdiesel.com](http://www.bluechipdiesel.com). At the web site you'll find more about the VP-44 than, perhaps, you wanted to know. The articles by Chip Fisher should be (and by nature of this reference, they are?) a part of our Perfect Collection.



The homepage at [www.bluechipdiesel.com](http://www.bluechipdiesel.com).

## 2003-Current HPCR Engines — Cranks, But No Start

As we move to newer models, troubleshooting can be progressively more difficult. With the older trucks we had solenoids, mechanical linkages, mechanical fuel transfer pumps, fuses and relays that we would check for proper operation. With the '03 and newer engines, the simple visible checkpoints are gone—the engine either fires up or it doesn't. What then, if it is a no-start? Begin with two basic checks:

- Just as we did with the '98.5–'02 24-valve engine, you will want to check the low pressure fuel delivery system and make sure that the electronic fuel transfer pump (on the side of the engine at the fuel filter assembly on '03-'04 and '04.5 trucks; inside the fuel tank on '04.5 trucks; inside the fuel tank on '05 and newer trucks) is operational. Bump the key to start (do not continue to crank) and release the key to run. Hop out of the truck and listen for the operation of the transfer pump.

- Check the power distribution center for a blown fuse.

From this point on it gets complicated. This is especially so as I try to offer tips on a printed page without being able to see or hear your engine.

Tracking a no-start is complicated by the fact that a no-start with the HPCR fuel system can mean it is time for a new set of injectors. I should mention that the TDR's Joe Donnelly did an all-encompassing article about injectors in a previous issue of the TDR (Issue 72, pages 44-57). This article is a part of our Perfect Collection.

## All HPCR Engines ('03-current), Long Story

Complaint: Long crank time on a '03-current HPCR engine.

Recently, a 2005 truck arrived with a hard starting problem. Other recent repairs included two remanufactured injectors, but shortly after the injectors were installed the owner complained the hard start problem worsened as did his poor fuel economy. The scan tool was connected and no diagnostic trouble codes (DTC's) were present. The batteries were tested and found to have a good charge. My next step was to monitor actual and desired rail pressure (psi) during the cranking attempts. After several consecutive cranking cycles the scanner showed pressure increasing from 1000 psi to about 4,000 psi at which time the engine started. Why will the truck not crank until a certain pressure level is met? Simple. At low pressure the ECM programming does not command the injector solenoids to energize. A light misfire was observed at engine idle.

The minimum rail psi for engine start is purposely not stated. Depending upon the scan tool manufacturer and the ECM programming of desired rail psi, it will vary. Likely much of the variance is due to how quickly the scan tool can respond and display a value. I have not personally observed a truck that would start while cranking with less than 2,000 psi. Usually the range is 4,300-5,800 on a known well running truck. Chrysler lists the rail operating pressures from 4,321 to 23,206 psi.

I suspected excessive injector return flow. Miller SPX service tool part # 9012 (see photo) was installed into the fuel return port on the right rear side of the fuel filter housing (item 4); then a length of fuel line was routed from the fitting to a five gallon diesel fuel can.



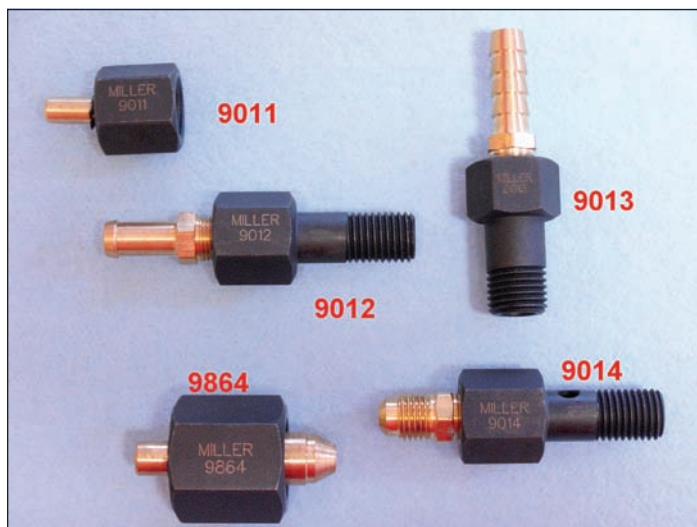
Looking at the 5.9 HPCR ('03-'07) fuel filter assembly:

1. Fuel supply line from the fuel tank to the fuel filter at the quick connect point
2. Fuel return line to fuel tank at quick connect point
3. Banjo bolt location for fuel rail and CP3 to return fuel to the system
4. Banjo bolt location for the fuel injectors to return fuel to the filter/fuel tank
5. Fuel return line

Another length of fuel line was routed from the fuel return line to a calibrated container. The total return flow after the engine idled one minute was 180 ml of fuel (or 6.1 oz.). This truck showed 443 ml /15 oz. of fuel after the test. This suggests one or more injectors is leaking into the return fuel passages (integral inside the cylinder head); there are improperly torqued injector connector tube retaining nuts (should be 37 ft-lbs); a cracked injector body; or fuel is leaking into the cylinders (usually causes white exhaust smoke). The injection lines were removed and the connector tube nuts were retorqued. All of the retaining nuts were under specification, with the two at the recently replaced injectors being significantly less than the desired torque specification.

The injector return flow test volume specifications/testing procedures have varied by model year and have been updated to include additional testing technique—such as the idle ramp up return test and the no start return test (see 2007, Factory Manual, TSB 14-003-06 and Warranty Bulletin D-05-24).

After the injection lines were reinstalled, the return test was again performed. The truck started with fewer cranking attempts to build required rail pressure. But, it still wasn't right. The engine idled one minute and 325 ml/11 oz. of fuel was measured in the container. This is still an excessive amount. Next, the injector lines were removed one at a time and the Miller SPX tool # 9011 (see photo) was installed at the rail. The engine will run on five cylinders while one line is blocked. The engine was started for one minute with each line consecutively removed, then reinstalled to test each injector. The calibrated container was closely measured for return fuel after each individual injector was block tested. The reason for this process of elimination is to isolate one or more injectors that have excessive return. A good injector should reduce total flow by not more than 40 ml or 1.4 oz., while one that returns too much fuel will negligibly reduce total flow (provided only one or two of the injectors return excessively) when blocked off. No single injector seemed to be the major leak source. Therefore, four remanufactured injectors were recommended. The total return flow returned to less than the 180 ml/6 oz. specification when retested. The truck built rail pressure quickly and started normally. The customer later stated that the "lost" fuel economy returned.



Miller SPX specialty tools.

### More HPCR Components to Check – '07-'11 No Crank

The late model common rail trucks are infamous for no-crank problems, although it usually is not related to fuel delivery problems, rather an electronic communication issue with the wireless control module (WCM) failing on a glitch, locking the truck into a theft mode. Occasionally a starter solenoid will fail, which prevents the starter from engaging albeit the starter being commanded to do so.

Sometimes the fix is simply to open the totally integrated power module (TIPM), your underhood fuse and relay center, and pull up on the IOD fuse (the one with plastic shrouding) waiting a couple of minutes then snapping the fuse back down (*ignition key must not be in the ignition switch*). This may reset the WCM and allow it not to falsely cause a theft deterrent situation, allowing the truck to start right up. Similar success by disconnecting both battery negatives and waiting a few minutes before reconnection has worked for me too. While the battery cables are disconnected press the horn button several times and cycle the headlamps, which may further drain modules stored power and memory.

It is advisable to see your dealer at your first opportunity or you may not be so lucky on the next occurrence, requiring an expensive tow to the dealer. The ultimate fix is to replace the WCM and reprogramming the SKIM (pin number for keys). TSB 08-007-08 Revision. A discusses this in more detail.

### Obscure Problem – Fan Clutch Short

If you have a common rail equipped truck, the electronic fan clutch can short, causing a cranks-but-no-start complaint. Either you or your technician will be frustrated by the lack of communication when you attach a code reader or scan tool and you don't find any trouble code(s). To troubleshoot this obscure problem, locate the fan clutch's electrical connector near the bottom left of the fan shroud. If disconnecting the connector restores communication and/or allows the truck to start, you've solved the problem. A replacement fan clutch will have you back in business.

Unlike the First and Second Generation trucks, the fan clutch is no longer left-hand thread. However, the wrench flats are the same size as in the earlier trucks. The truck's fan clutch clearance is quite tight, but once the clutch is loose and the four shroud posts are loosened, the shroud can be pried back towards the engine, so that the fan/clutch can be removed. Resist the urge to purchase the inexpensive Hayden fan clutch, rather ante up for the Mopar unit. I refuse to install a Hayden because I've had so many that did not work.

### CONCLUSION

Well, gang, how is that for trying to cover a lot of different problems spread over five distinctly different engines? Seriously speaking, I've just touched on some of the basics. Down here in Texas you wouldn't believe the damage rodents can do to electrical parts and rubber. Likewise, I rarely see temperatures below 20°. I'm betting owners in Alaska, Canada and other frigid areas have a number of other stories to tell. Nonetheless, I'm hopeful this 8-pages will help you the next time the truck refuses to cooperate.

**Andy Redmond**  
TDR Writer

# Lube Oil Filters

ISSUE 71

## LUBE OIL FILTRATION UPDATE

by John Martin

### Background

Robert Patton asked if I would update Arden Kysely's TDR "Oil Filter Buyer's Guide" published in TDR Issue 32 (summer 2001). First, let me say that Arden did an excellent job of comparing 13 oil filters for the 12-valve engines. This article has been posted at the TDR and Geno's Garage websites. If you are not familiar with the basics (i.e. paper/cellulose design versus synthetic filter media) you'll want to read (reread) Arden's entire article. The basics have not changed. However, we all know that the more things change... well, do they stay the same? Yes, indeed, it is time for an update.

Before starting, let me give you a little of my background qualifications to write an article on lube oil filtration. I'm a physicist by training (M.S., Engineering Physics), so I need to understand how things work. I worked over thirty-three years as a fuels and lubes scientist, and I have ten patents in my name. Three of them are for lube oil filtration developments. I authored a series of articles for Fleet Equipment Magazine (December 2008, January 2009, February 2009) on lube oil filtration.

Prior to retiring from the Lubrizol Corporation, I was selected to be a member of a small team charged with evaluating a filtration company for possible purchase by Lubrizol. One of our business development people had identified a filtration company they wanted to purchase, so the Senior VP of Research and Development asked our team to evaluate and make recommendations.

A core group of three of us traveled to various filter suppliers so we could compare their facilities. What we learned was truly amazing! First, like lube oils, passenger car filtration has become a commodity industry due to competitive pressures. For example, large purchasers such as Wally World (that's slang for Walmart) more or less tell oil filter manufacturers that the amount of shelf space they will obtain is indirectly proportional to the cost of their filters. That's why you see a lot of Fram filters at Wally World. Heavy duty filtration science was better.

## Oil Filter R&D

Again, as part of our team's research we traveled to virtually all of the major players' R&D facilities. I have better R&D in my shop than a few of the manufacturers. In fact, the VP of Research for one well-known truck filter manufacturer told me his research philosophy. He said, "I look at what Fleetguard has recently patented, and I try to figure out a way around the patent." Research expenditures at most filtration manufacturers are less than 1% of sales. Many simply purchase media from a media supplier and produce filters without conducting anything more than basic confirmation testing.

Before you draw the conclusion that all filter manufacturers are a bunch of hacks (One of my oil filter manufacturer buddies calls them filter whores.), let me give you some more encouraging information. Manufacturers of higher end filters (such as industrial and medical) spend much more on basic filtration research. Companies such as Donaldson, Fleetguard, and Pall have extensive research facilities. In their defense, I was unable to visit Wix's facilities, but I've heard from others that they are also a cut above the rest. In fact, NAPA makes no secret of the fact that Wix has supplied their filters for years. This is not uncommon. If a marketer wants to supply an oil filtration product, he will often contract with a filter manufacturer to simply rebrand their product. Filter manufacturers also make filters for each other when this is necessary to help control availability and/or cost. Filters are much too heavy to be shipped all over the world.



Here is the line-up of filters to evaluate.

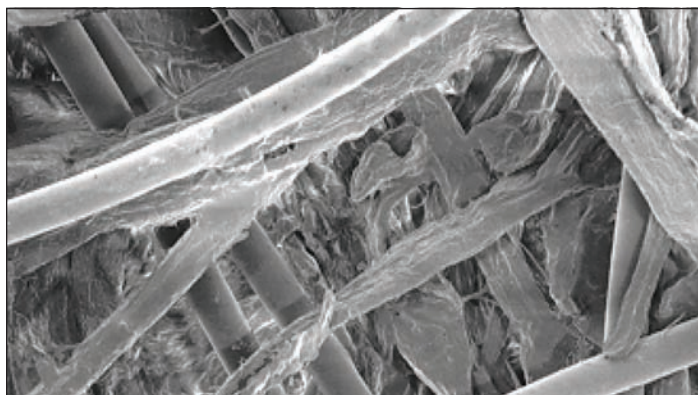
## Oil Filtration Fundamentals

As I said before, Arden did an excellent job with his oil filter comparison in TDR Issue 32. I really enjoyed his comparison of the paper/cellulose and synthetic filter media. Three main things to remember here are: (1) Synthetic media can be engineered to remove finer particles while still maintaining good oil flow, (2) Synthetic media has the capacity to hold more dirt than paper/cellulose media due to the smaller cross-sectional area of the media fibers, and (3) Synthetic media costs approximately three times as much as paper/cellulose media.

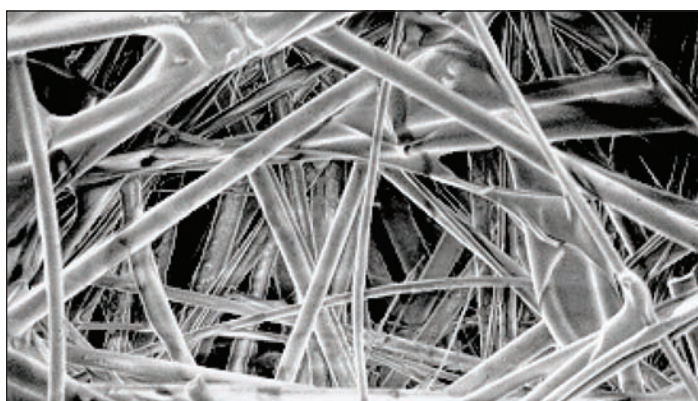
Now, I know that twice I've made reference to Arden's Issue 32 article. I also know the editor sent several copies to me, so it was easy to read about paper/cellulose versus synthetic filter media.

Finally, I know you'd rather I give you the "Cliff Notes" version of the article 'cause it is quite the interruption to get out of the EZ chair and fire up the internet. So, here goes:

Logically you think that in order to remove finer particles that there would be restriction to oil flow. As mentioned, that is not the case with the synthetic media. To understand this, the Fleetguard tech service guy told me to draw a bunch of random, intersecting lines on a paper. Do so and you'll see small gaps here and large gaps there. That is what the paper/cellulose media looks like under magnification. Now, to visualize the synthetic media, draw uniform vertical and horizontal lines on the paper. With the uniform pattern you can visualize how the synthetic media gives better filtration and better flow. Got it?



Cellulose filtration media.



Stratapore synthetic filtration media.

Now let's discuss a few more oil filtration fundamentals. First, the Glacier Metals Corporation did a landmark study of foreign particle size versus engine wear in the '70s. They concluded that the majority of engine wear was caused by particles in the 5 to 15 micron\* size range. Larger particles were easily filtered out, and smaller particles traveled through the lubrication system without causing significant wear. I suspect the closer engine clearances of today might serve to tighten up this average particle size range to 3 to 12 microns\*.

Secondly, oil filters for today's diesels have to handle significantly higher soot levels in the oil. Soot loading of the oil in EGR-equipped engines is 4-5 times as much as it was in the '70s. Lube oil formulators have doubled the concentration of ashless dispersants in diesel engine oils to keep the soot particles small so they will remain in suspension. Most soot particles with modern oils in modern engines are less than 1 micron in diameter, making it difficult to filter significant soot particles out of the oil.

A full-flow oil filter is, by design, constructed to filter 100% of the oil coming out of the oil pump. In order to accomplish this, filter manufacturers have to compromise on the porosity of their filtration media so the filter will not plug before the end of the oil change interval. Most modern full-flow oil filters are best at removing particles in the 20 to 40 micron size range.

So, what does all this mean? Modern diesel engines will run for many miles before abrasive engine wear becomes a problem. But, if you want the ultimate in oil filtration, you might want to consider "bypass filtration." Bypass is actually a misnomer, because it is often confused with an oil filter being bypassed because it is plugged. Bypass or secondary oil filtration actually takes about 10% of the oil stream and diverts it through a much finer filter which won't interrupt engine oil supply if it should plug.

Bypass filters can effectively filter particles as small as 1-2 microns, but they are very expensive and take additional labor to install. By the way, bypass filters don't filter fine enough to remove engine oil additives from the oil, because these particles are usually less than 1 micron in diameter. Most truckers don't use bypass filtration because they don't feel the benefits outweigh the added cost and complexity. I agree with their assessment in most instances.

If you want to read about a bypass filter for your engine, pull out TDR Issue 65, page 100. And, for grins, note that the editor and I agree about the assessment of total cost. Likewise, you can read this sidebar that Robert wrote on page 69 about the "Ideal John Martin Filter." Agreement with the editor: gotta keep these part-time writing assignments coming in, ya' know.

**\* Keep these micron numbers "5 to 15" fresh in your mind while you read the sidebar "What is a Micron".**

## Oil Filter Specifications

When a filter manufacturer develops a filter to rebrand for an OEM (such as Cummins, Mopar, Motorcraft, AC/Delco, etc.), the OEM usually has a very specific battery of demanding tests they want the candidate filter to pass before they will allow their brand name/corporate logo on the box. Sometimes these tests are exhaustive. Caterpillar, for example, used to require a fuel filter which could remove much finer particles than all the other diesel engine manufacturers' fuel filters because they utilized tighter clearances in their fuel system and deemed that finer filtration was necessary.

I asked a Donaldson engineer to supply me with a list of tests which are used to validate oil filter performance. There are at least ten tests that filter manufacturers use to ensure that their products offer sufficient performance, durability, fluid compatibility, and media integrity. I thought it was particularly interesting that synthetic filtration media have a distinct advantage on two of the tests (Multipass ISO 4548-12 and Pressure Drop SAE J1985) due to their smaller fiber cross-sectional areas.

However, filters which go into the aftermarket often meet only basic minimum test standards. Some filter manufacturers conduct only those tests which they feel will ensure a consistent, safe product for them to market. Then that filter manufacturer relies on exaggerated marketing claims on the box which are often meaningless. For

example, the STP S3976 filter, which is manufactured by Champion Laboratories, is a good example. This filter is undoubtedly the lowest-quality oil filter in our study, yet the box claims it has 20% more filtration capacity than the leading brand. Horse hockey! This filter has the least amount of media (in terms of both the length of the filter element and the number of pleats in the media) of all the filters we evaluated. NAPA's oil filter and O'Reilly's house brand Microguard filter (MGL 3976A), which both retail in the same price range (\$5-\$6), have over 20% more media surface area.

But, I'm getting ahead of myself. A little more background: The editor sent me an oil filter cutter and a bunch of oil filters to cut up and told me to quit taking naps (That semi-retirement thing, ya' know?) and get to work. Now I'll be the first to admit that cutting an oil filter apart can't tell you everything you need to know about that filter, but it can certainly give you an indication of the construction ethics and habits of those who built the filter. I bought some additional filters, lined them up on one of the ramps of my hoist, and cut filters like an ax murderer on steroids. Table 1 contains the data I collected on the ten cellulose filters I examined, while Table 2 contains the data I obtained on three partial synthetic filters. Table 3 is my full synthetic filter comparison data. Table 4 shows you where I obtained my selling price information.

Spend as much or as little time on the tables as you see fit. I think you'll enjoy my observations that follow the tables.

**TABLE 1: OIL FILTER COMPARISON (CELLULOSE MEDIA)**

| BRAND              | Mopar         | Fleetguard | Donaldson     | NAPA     | Fram               | Microguard | K&N                              | Super Tech.       | STP               | Purolator |
|--------------------|---------------|------------|---------------|----------|--------------------|------------|----------------------------------|-------------------|-------------------|-----------|
| Part #             | M-285         | LF3972     | P558615       | 7620     | 3976A              | MGL3976A   | HP4003                           | ST3976A           | S3976             | L45335    |
| Where Produced     | Mexico<br>USA | Mexico     | USA           | USA      | China<br>Mexico    | USA        | USA                              | USA               | USA               | USA       |
| Price, Vendor*     | 13.09 AA      | 7.95 GG    | 7.50 NH       | 11.29 NA | 5.99 AZ<br>5.99 OR | 4.99 OR    | 13.99 AA<br>13.99 AZ<br>13.99 OR | WM                | 4.99 AZ           | 5.49 AA   |
| <b>Element:</b>    |               |            |               |          |                    |            |                                  |                   |                   |           |
| Length, in.        | 5-5/8"        | 5-5/8"     | 5-11/16"      | 5-11/16" | 5-11/16"           | 5-3/4"     | 5-5/8"                           | 5-11/16"          | 5-7/16"           | 5-7/8"    |
| Dia., in.          | 3-3/8"        | 3-3/8"     | 3-5/16"       | 3-7/16"  | 3-3/8"             | 3-3/8"     | 3-5/16"                          | 3-3/8"            | 3-3/8"            | 3-3/8"    |
| # of Pleats        | 64            | 67         | 57            | 49       | 57                 | 55         | 57                               | 57                | 41                | 64        |
| <b>Can:</b>        |               |            |               |          |                    |            |                                  |                   |                   |           |
| Length, in.        | >6            | >6         | >6            | >6       | >6                 | >6         | >6                               | >6                | <6                | >6        |
| Wt., oz.           | 8             | 8          | 6             | 7        | 6                  | 5.5        | 7                                | 7                 | 7                 | 7         |
| Flutes             | yes           | yes        | no            | yes      | no                 | no         | nut                              | no                | yes               | yes       |
| <b>Base Plate:</b> |               |            |               |          |                    |            |                                  |                   |                   |           |
| Wt., oz.           | 8             | 8          | 7             | 7.5      | 7.5                | 7.5        | 8                                | 8                 | 7                 | 8         |
| Holes              | 8-3/8"        | 8-3/8"     | 8-5/16"       | 6-5/16"  | 6-3/8"             | 6-3/8"     | 7-1/4"<br>1-5/16"                | 7-1/4"<br>1-5/16" | 5-1/4"<br>1-5/16" | 8-1/4"    |
| <b>Sealed by:</b>  |               |            |               |          |                    |            |                                  |                   |                   |           |
| Spring             | coil          | coil       | coil          | coil     | coil               | stamped    | stamped                          | stamped           | stamped           | stamped   |
| Gasket             | rubber        | rubber     | molded rubber | plastic  | plastic            | rubber     | none                             | none              | none              | none      |

\*Vendor Code: AA Advance Auto  
AM Amazon.com  
AZ Auto Zone

GG Geno's Garage  
NH New Haven (Local Parts House)  
NA NAPA Auto Parts

OR O'Reilly's Auto Parts  
WM WalMart

## The Analysis

I've grouped several filters together: the Mopar and Fleetguard; the Fram and Microguard; the K&N, Super Tech and STP. (Heavy vertical lines in the comparison chart group these together.) Casual observation shows that these are the same filter with different exterior paint and logos.

Such, too, was the conclusion for many of the filters back in Issue 32. Again, saving you from the task of research, Arden noted the following observations of the same filter/different logo:

- Mopar, Fleetguard and Motorcraft (coil spring)
- Wix, NAPA and Penske (coil spring)
- Hastings and Purolator (coil spring)
- Deutsch, K&N, Mobil 1 (stamped spring)
- Fram (stamped spring)

In my evaluation, the cast of characters has changed somewhat, but as a quick and easy (and, yes, unscientific) judge of quality you can bet I'll not be using a filter with a stamped-type spring. In terms of then and now, it looks like the Purolator folks have changed their supplier as they are now in the stamped spring category. Further commentary on cellulose filters follows. I wonder if Purolator would still be on the recommended TSB list (TSB 09-004-01) if it were rewritten today? (For an explanation of the TSB skip to page 64.)

## The STP Oil Filter

As previously mentioned, the STP filter is made by Champion Laboratories. The STP oil filter has a base plate which has only five 1/4" diameter holes and one 5/16" diameter hole for the inbound oil to flow through (as Arden said, "In around the outside, out

through the inside"). Taking wall effects into account, this means the STP filter will flow no more oil than a 1/2" diameter hole. Slowing oil flow is a method used to allow the media more time to filter the incoming oil, and it is often used in bypass filtration. But, are you certain your engine is getting sufficient oil flow to protect all of its components? In addition, the STP filter uses an inexpensive, stamped steel spring and no gasket to load and seal the filter element (or cartridge) against the base threaded plate. I previously mentioned the marketing claims, and STP has a clearly established brand name. (I struggle to understand what the STP brand represents.) In my opinion the STP filter is clearly the lowest quality of all the filters I evaluated.

## The K&N Oil Filter

Since I've gone on such a rant about Champion Laboratories' products, let's continue with a discussion of the K&N oil filter (HP-4003). It uses the same base plate, but with seven 1/4" diameter holes and one 5/16" diameter hole to improve oil flow into the filter element. Since some racers use higher viscosity lube oils, this makes perfect sense. It also uses the stamped steel spring to seal the filter cartridge against the base plate, again without a gasket. I had two of these filters, and one of them rattled because the filter element wasn't tight against the base plate. This means that particular filter would not be filtering 100% of the oil going into the housing. I've always had a high opinion of K&N's air filtration products. However, I'm going to pass on their oil filter (\$13.99 at Advance Auto, Auto Zone, and O'Reilly's), because it is overpriced, and their quality control is lacking. It does have a nut on the can if you should require an oil filter which can be safety wired to prevent loosening. (Some racing organizations require this.)



Inspection of the STP filter shows the limited number of holes in the base plate, the stamped metal spring to preload the cartridge, and the minimal number of pleats in the filtration media.



The very expensive K&N oil filter is made by the same people who made the Mobil and STP oil filters.

## The Fram Oil Filters

I usually expect Fram filters to be at the bottom of the barrel, quality wise, because they have been living off their brand name for some time now. And the Fram Tough Guard partial synthetic (TG 3976A) filter (\$6.99 at Auto Zone and \$8.98 at Walmart) didn't let me down. It uses the stamped steel washer to seal the filter element to the base plate (this time with a gasket) and a very light, non-fluted can. It had only three more pleats than the Mobil partial synthetic filter, yet it claims six times more engine protection than the leading economy brand. Again, what does partial synthetic mean?

However, I was truly surprised by the two baseline Fram filters (PH3976A). These are Fram entry level filters which sell for \$5 to \$6 at various locations. When I cut them apart, I observed a higher-quality filter with a coil spring to load the filter cartridge against the base plate and a gasket to make sure the parts are sealed. Although one filter was made in China and the other in Mexico, these filters were mid-range or above in their construction quality. I immediately called Robert to see what he might know about these Fram filters.

It seems that numerous Cummins B series engines equipped with entry level Fram filters suffered piston failures some time back (years 1999, 2000). Upon investigation it was found that the piston undercrown oiling tubes (official term: piston cooling nozzles) were plugged, which caused the pistons to overheat and scuff against the cylinder walls. Cummins found that these oilers were plugged by some of the glue or resins used in the Fram filters, so they sent Fram a bill for those engines. You don't want to screw with diesel engine manufacturers' products, because their reputations are very important to them. Fram immediately upgraded the quality of this filter for use on the Cummins B series engine. Kudos to Fram for this one filter. ***\*Editor's note: Documentation of Fram's filter follies (follies: as nice a term as I could find) is found in TDR Issue 34, page 105. As a result of their follies, Dodge issued a technical service bulletin (TSB 09-004-01 dated 5/18/01) which informed the service network of the recommended oil filters for the Turbo Diesel engine. The approved manufacturers were (again the date of the TSB is May 2001):***

**Mopar  
Fleetguard  
Motorcraft  
A/C Delco  
Purolator**

## The Remaining Cellulose Oil Filters

Now let's discuss the remaining entry-level cellulose filters. First, I wouldn't use a cellulose filter if I were contemplating extending oil change intervals, because water in the oil can cause the cellulose media to sag and eventually rupture over long periods of exposure. They are fine if you don't overextend them. This is an even more serious problem if you burn ethanol fuels because alcohol in the oil sucks up and entrains significant water. You must use synthetic media in these situations, because synthetic media is impervious to water damage.

Secondly, I wouldn't use a filter which depended on a stamped steel (Belleville) washer to load the filter element against the base plate in a heavy duty application. Oil pressure in an engine can be

very high at startup, and it often fluctuates wildly as the engine is operated because some oil pumps have lobes which cause pressure fluctuations as engine oil is pumped through the system and the oil pump pressure relief valves are rapidly opened and closed. If you consider a stamped steel spring and a coil spring as if they were stretched out lengthwise side by side, it's easy to visualize that the stamped steel spring only has one or two inches over which it can absorb a given pressure fluctuation without exceeding its elastic limit. The coil spring, on the other hand, has several inches of steel over which it can absorb those same pressure fluctuations. Stamped steel springs will exceed their elastic limit much more easily than coil springs, and all preload against the base plate will be lost. Then your oil won't be totally filtered. Since the Microguard (I'm sure it's made by Fram); Purolator (L45335); STP; and Super Tech ST 3976A and K&N (I'm sure they are made by Champion Labs) filters contain stamped steel springs, I wouldn't recommend their use.

## My Cellulose Oil Filter Picks

This leaves us with the Donaldson P558615 (\$7.50 at New Haven filters), the Fleetguard LF 3972 (\$7.95 at Geno's Garage), the Mopar MO-285 (\$10.47 at Walmart and \$13.09 at Advance Auto), and the NAPA 7620 (\$11.29 at NAPA). The Donaldson filter was unique in that it used a formed rubber gasket and heavy coil spring to seal the element against the base plate and a well designed, threaded base plate with eight oblong 1/4" wide holes. I think the resultant flow rate would be equivalent to at least eight 5/16" diameter holes. It was also the only filter I received sealed in a plastic wrapper. Both the Fleetguard and the Mopar filters use heavy threaded base plates with 8, 3/8" diameter holes, fluted cans, rubber gaskets, and heavy coil springs to seal the element against the base plate. ***Editor's note: In the case of oil and fuel filters, for all model year trucks, it is a fact that Fleetguard makes the filters for Mopar.*** These are my three favorites, and I would pick the Donaldson or Fleetguard filters basically because of the price. Some times it's hard to find Donaldson filters, because they mainly cater to the heavy duty market (look for a truck parts or filtration distributor).

The NAPA 7620 (\$11.29 NAPA) is also a well built filter with a plastic gasket (not quite as good as a rubber gasket) and fewer holes in the base plate. It also has less filtration capacity because it has approximately 20% fewer pleats in the media. It's probably still a perfectly good filter. As a point of interest, the NAPA 1607 filter uses the same components in a non-fluted can for about \$0.60 less. I just prefer one of the first three I mentioned because they appear to be better constructed filters.



**My cellulose filter picks – the Donaldson, Fleetguard, Mopar, and NAPA Filters.**

## SYNTHETIC OIL FILTERS

So, after cutting up 15 filters (10 cellulose, 3 partial synthetic, 2 full synthetic), it is time to evaluate the two synthetic filters that were easy to find and purchase. This should come as no surprise to you, my favorites from this entire test are both the Fleetguard LF16035 (\$12.95 at Geno's Garage) and the Wix 557620XE (\$10.49 at O'Reilly's). I don't see how you could go wrong with either of these filters, and the extra \$5 you would pay for the synthetic filter is cheap insurance. I'm sure Donaldson also produces a synthetic filter for this application, but I just didn't have one to evaluate. I only wish I could purchase this quality of oil filter for my passenger cars.

I'm not going to recommend any of the partial synthetic filters for several reasons. As I said before, the Mobil filter is a cheaply constructed, over-priced filter that isn't worth the money they ask for it. The Fram Tough Guard might be a cut above the Mobil filter, but it still uses a stamped steel washer to preload and seal the filter element against the base plate. The Purolator Pure Oil filter is probably the best of the three, but the only price I could find was \$17.99 at Advance Auto. That's a hell of a price to pay for a metallic blue painted can! I recommend you also steer clear of partial synthetic oil filters until more exacting specifications are developed to identify the synthetic fiber content and categorize the performance of these new generation filter designs.



Note the small 1/4" holes in the Mobil and STP base plates.

TABLE 2: OIL FILTER COMPARISON (PARTIAL SYNTHETIC)

| BRAND                  | Fram Tough Guard           | Mobil M1                         | Purolator Pure One |
|------------------------|----------------------------|----------------------------------|--------------------|
| Part Number            | TG3976A                    | M1-403                           | PL45335            |
| Where Produced         | USA                        | USA                              | USA                |
| Price, Vendor*         | 6.99 AZ<br>8.98 WM         | 10.99 AA<br>11.99 AZ<br>12.99 OR | 17.99 AA           |
| <b>Filter Element:</b> |                            |                                  |                    |
| Length, inches         | 5-11/16"                   | 5-1/2"                           | 5-7/8"             |
| Diameter, inches       | 3-3/8"                     | 3-5/16"                          | 3-3/8"             |
| Number of Pleats       | 57                         | 54                               | 64                 |
| <b>Can:</b>            |                            |                                  |                    |
| Length, inches         | >6                         | 6                                | >6                 |
| Weight, ounces         | 5.5                        | 7                                | 7                  |
| Flutes, Yes or No      | no                         | yes                              | yes                |
| <b>Base Plate:</b>     |                            |                                  |                    |
| Weight, Ounces         | 7.5                        | 7.5                              | 8                  |
| Holes                  | 6-3/8"                     | 5-1/4", 1-5/16"                  | 8-1/4"             |
| <b>Can Sealed By:</b>  |                            |                                  |                    |
| Type of Spring         | stamped                    | stamped                          | stamped            |
| Type of Gasket         | rubber                     | none                             | none               |
| Claims                 | 6 x more engine protection | 2 x more capacity                |                    |

### \*Vendor Code

|    |                                        |
|----|----------------------------------------|
| AA | Advance Auto                           |
| AM | Amazon.com                             |
| AZ | Auto Zone                              |
| GG | Geno's Garage                          |
| NH | New Haven ( <i>Local Parts House</i> ) |
| NA | NAPA Auto Parts                        |
| OR | O'Reilly's Auto Parts                  |
| WM | Walmart                                |

## A LOOK AT PARTIAL SYNTHETIC FILTERS

The term “partial synthetic oil filter media” reminds me of partial synthetic lube oils. In the case of engine oils, mineral oils have a distinct definition, and fully-synthetic oils have an industry accepted definition. But stating that an oil is a partial synthetic could mean anything. There is no industry accepted definition of a partial synthetic motor oil. My oil filter engineer contacts say the same is true of oil filters. There is no accepted definition of a partial synthetic oil filter. Do these oil filters contain 5% or 75% synthetic fibers?

Besides the STP oil filter, the only other filter in our study with so little flow through the base plate was the Mobil M1-403 partial synthetic oil filter, which sells for between \$10.99 at Advance Auto and \$12.99 at O'Reilly. This filter, which is also produced by Champion Laboratories, also utilizes a stamped steel spring to load the filter cartridge against the base plate, again with no gasket to seal the cartridge to the base plate. As with the STP filter, the filter element is smaller than the competitive offerings, and the number of pleats in the media is at least 5% less than any of its competitors. The Mobil filter claims it removes more contaminants and has two times the filtration capacity of the leading brand because the filter media is a partial synthetic. Don't believe everything you read! I wouldn't trust this filter for use on my Cummins engine.

Before I would pay that kind of a price for an oil filter, I would purchase a fully-synthetic Wix (\$10.49 at O'Reilly) or Fleetguard (\$13.13 at Amazon.com or \$12.95 at Geno's Garage). I suspect that Donaldson also makes one of their Endurance synthetic oil filters for this application, but I don't know.



**My synthetic filter picks – the Fleetguard and Wix filters.**

After completing this study, I'm anxious to cut apart some passenger car automotive oil filters. I usually don't give it a lot of thought when I purchase oil filters for my cars, but I think I'm going to now.

**John Martin**  
TDR Writer

**TABLE 3: OIL FILTER COMPARISON (FULL SYNTHETIC)**

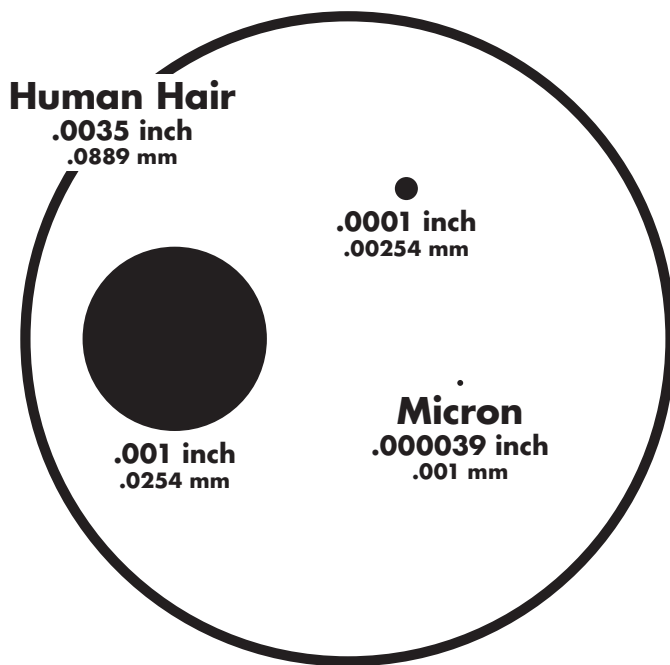
| BRAND                  | Fleetguard           | Wix      |
|------------------------|----------------------|----------|
| Part Number            | LF16035              | 557620XE |
| Where Produced         | USA                  | USA      |
| Price, Vendor*         | 12.95 GG<br>13.13 AM | 10.49 OR |
| <b>Filter Element:</b> |                      |          |
| Length, inches         | 5 5/8                | 5 5/8    |
| Diameter, inches       | 3 3/8                | 3 3/8    |
| Number of Pleats       | 47                   | 47       |
| <b>Can:</b>            |                      |          |
| Length, inches         | >6                   | >6       |
| Weight, ounces         | 6.5                  | 7        |
| Flutes, Yes or No      | yes                  | yes      |
| <b>Base Plate:</b>     |                      |          |
| Weight, Ounces         | 8                    | 8        |
| Holes                  | 8-3/8"               | 8-3/8"   |
| <b>Can Sealed By:</b>  |                      |          |
| Type of Spring         | coil                 | coil     |
| Type of Gasket         | rubber               | rubber   |

## WHAT IS A MICRON

by John Martin

Good question. For the answer I went to Fleetguard's web site ([www.fleetguard.com](http://www.fleetguard.com)) for the definition. **(Editor's note: an understanding of this term is easy to comprehend; an understanding of its value in evaluation filter performance is convoluted by marketing hype and nonsense.)** So, the answer is, "A micron is a thousandth of a millimeter or a millionth of a meter or .000039 of an inch. Micron is the unit of measure used to determine the size of particles in a fluid which are filtered out by the filter."

# How big is a Micron?



Now, to address the hype and nonsense that the editor referred to: the question often comes up, "What is the difference between Absolute and Nominal micron rating? The micron rating is the size of particles which are filtered out by filters at a certain efficiency. When this efficiency is at least 98.6%, we speak about absolute micron rating/filtration. Nominal micron rating is just a commercial trick for all efficiencies lower than 98.6%, meaning that for the same micron rating (for example 10 micron) in the case of nominal rating, not all particles will be captured in the filter as in the case of absolute micron rating."

So, when a product (most often it is in a fuel filter discussion) has a claim of "3 micron filtration," you have to stop and ask, "3 micron, what, Absolute or Nominal?" If the answer is nominal, the answer is meaningless.

To further complicate matters, Fleetguard and other manufacturers don't publish micron ratings for all products. But, in a backdoor kind of way I can tell you from research at Fleetguard's Frequently Asked Questions (FAQs) for lube oil filters that, "in full-flow lube oil filters, Cummins Filtration uses cellulose media (40 micron absolute) or upgrade media, such as StrataPore (25 micron absolute)." How does this compare with all the other oil filters? I wish I could tell you, but, as I mentioned a few sentences ago, manufacturers don't actively publish ratings for all of their products.

## The 25 to 5 Range of Particles

Now, here is a concern that I have. If the Fleetguard cellulose (good at 40 micron) and Fleetguard Stratapore (best you can purchase in the industry at 25 micron) get us only to 25 micron absolute, and my research and conclusion earlier that "the majority of wear is particles in the 5 to 15 range," how do I get protection between the 25 to 5 range? Better yet, there are thousands of cars and trucks with 100,000 milestones on engines, is the 25 to 5 range protection needed? I was asked to do some more research. The following is what I found.

First, let's examine how particles are filtered out of a liquid. Most of us immediately think of a strainer and then postulate that a strainer can only filter out those particles which are too large to go through the openings in the media. Well, that's one filtration mechanism (surface filtration); but one must realize that if two particles having diameters larger than half the diameter of the opening arrive at the opening at precisely the same time, they will also be filtered out because they can't get through the opening.

A second and equally important filtration mechanism is often referred to as the tortuous path mechanism (depth filtration). Remember the old oil bath air filters on '30s and '40s cars? Particles cannot (due to their higher density) be expected to turn a corner as tightly as the air or liquid they are in. The particles hit the walls of the filter and are captured. The deeper the filtration media, the more effective it is.

Of course, the more particles filtered, the more efficient the filter becomes until it eventually plugs completely. So, effectively, a dirty filter is better than a clean filter. I know, counterintuitive, but it is a fact. This causes a constant balancing act for filter designers, particularly those for diesel engines. Modern diesels generate a tremendous quantity of soot particles. If filter designers try to remove too many of these particles, the filter will plug completely before the end of the oil change interval.

Now, back to my 25 to 5 range concern. I called my engineer buddies at Donaldson and asked them if they could shed any light on the Fleetguard ratings for their cellulose media (supposedly only filtered as fine as 40 microns) and the synthetic media (supposedly filtered only as fine as 25 microns).

He said this is the problem with using micron ratings to rate filter performance. The accepted industry definition is that 98.6% of the particles of that particular size must be removed to say the filter can filter particles that small (the definition of the absolute micron

rating). However, smaller particles are removed as well. A filter which removes 98.6% of the 40 micron particles passing through it also removes progressively lower percentages of 30, 20, and even 10 micron particles (the smaller the particle, the lower the percentage). So, the 25 to 5 range of particles is being filtered; we just can't quantify the number.

This is another advantage for synthetic filtration media. Cellulose media tends to function more like a strainer (surface filtration) while synthetic media can be designed to filter particles both at the surface and down into the media (depth filtration). As a result, Fleetguard's 25 micron synthetic media (brand name Stratapore) filter probably removes more than twice as many particles in the 10-15 micron size rating as their 40 micron rated cellulose media filter. Yet another reason to purchase synthetic oil filters—not partial synthetic!

One last word about microns and ratings: Just as the public frequently uses a terminology (micron rating), the industry goes and reinvents itself with new and better tests. In vogue now are the "Beta Ratio and the ISO Code" test procedures. But, since I've already added confusion enough for one sitting with the TDR magazine, I'll refrain from further discussion on these tests. Let's save Betas and ISOs for the future.

**John Martin**  
**TDR Writer**

**FLEETGUARD'S VENTURI OIL FILTER**  
*or*  
**THE \$45 OIL FILTER**  
*or*  
**THE IDEAL JOHN MARTIN OIL FILTER**  
by Robert Patton

Recently a TDR member called to ask if I knew about Fleetguard's Venturi Combo Oil Filter. My response, "Venturi, has that got anything to do with the Hollywood movie, 'Ace Ventura' or with politico Jessie Ventura?" Obviously, I needed to do some research.

The facts: Fleetguard offers a Venturi oil filter that was designed for B-series engine applications in Kubota equipment. Fleetguard also offers about 25 other part numbers for their Venturi product to fit other diesel engine applications (Caterpillar, Detroit Diesel, Cummins, Lomatsu, Hitachi, Ford Powerstroke, etc.). The part number for our application is LF9028 and the retail price is about \$45. So, at \$45 this oil filter had better be something special, right? And, special it is. The Venturi Combination Oil filter has a unique internal flow that is achieved with a Venturi nozzle that directs a portion of the oil to a stacked bypass media to capture soot and sludge. The balance of the lube oil flows through the full flow section that uses Stratapore material to filter the contaminants. The Venturi combo filter was designed to help fleets extend their oil drain intervals and the testing done by Fleetguard shows oil drain intervals; on severe duty Australian Road Trains were up to two times longer, extending out to 75,000 miles. This sounds like the ideal "John Martin oil filter," at least until you factor in the cost of the filter and the manufacturer's recommended oil change intervals for your engine.

First "bottom line:" Dodge is the authorized warranty agent and their recommended oil and filter products require maintenance at the intervals set forth in your Owner's Manual. In your selection of oil and filters, can you use better products? Without a doubt, but unless you want the responsibility of acting as the warranty agent you cannot ignore Dodge's maintenance intervals.

Second "bottom line:" See first bottom line and bypass products and filters like the Venturi became cost prohibitive. As John said, you have to do extended oil drain intervals to make the dollars invested worthwhile.

Third "bottom line:" See first bottom line and know that without a doubt you can use better products for your engine than those that are set forth and recommended in the Owner's Manual. Consider the second bottom line, and making the dollars invested in the maintenance of your truck worthwhile. Now, ask yourself this question "Using the recommended products and service intervals are owner's experiencing problems with engine wear-out? If I invest in better products will I be the benefactor of the extended life? Or, will my efforts to extend engine life be negated when the truck is traded/sold to someone and subsequently over-heated, over-fueled or wrecked?

Conclusion: The answers to these "bottom line" series of questions are as unique as each individual truck owner. I think I'll play it safe by sticking to the recommended service intervals and use the good quality Stratapore oil filter (yes, I can justify \$5 additional cost). For oil... well, the generic works for me. Do John Martin's series on lube oils in Issues 54-58 warrant your reread?

**Robert Patton**  
**TDR Staff**

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NOTES:

# G56 Rebuild

ISSUE 71

## REBUILDING THE G56 SIX-SPEED TRANSMISSION

by Joe Donnelly

The six-speed manual transmission for the Turbo Diesel was changed by Dodge from the New Venture 5600 that had been used since 1999 until late in the 2005 model year, to a Mercedes Benz unit, the G56. The G56, as we are now aware, is an aluminum cased six-speed with integral bell housing, and a new (for Dodge) design dual-mass flywheel. The Chrysler noise/vibration/harshness engineering group wanted to “elevate the customer experience” with the change in flywheel design. The G56 shifts easier and smoother, but reaching reverse seems easier with the NV5600 than the G56. Initially, the overdrive was not as steep (0.79 versus 0.73 for the NV5600) in the G56, but there was a change to an overdrive ratio of 0.74 in a new version of the G56 for the 6.7-liter Cummins (2007.5 year model). The early input shaft has two grooves, which can be seen by removing the front bearing retainer (a stamped steel part that costs \$159) (photo 71-15). The late ratio input shaft has three grooves (photo 71-16). More reports of noise seem to be associated with the later design. A fairly large number of sixth gear failures have occurred, and it may be that the mild 0.79 overdrive ratio causes more drivers to use sixth gear when towing heavy trailers, when direct drive (fifth gear) should be used.



71-15 Early G56 input gear (0.79 overdrive ratio) and front bearing retainer.



71-16 Late G56 input (0.74 overdrive).

The dual mass flywheel has been problematic. At the time Dodge introduced it, Peter Pyfer of South Bend Clutch described issues with the Duramax version of Luk's dual mass flywheel, and the scope and limitations of the concept (Issue 53, page 98). Specifically, the Luk design experienced some failures and was strengthened, but he felt the Dodge version was similar to the Duramax and “the problem was, and still is, not resolved.”

Now, five years later we find that the South Bend clutch conversion (see Issue 68, page 88) is a “standardized” replacement for the OEM dual mass flywheel and clutch. Performance of the G56 has been flawed, according to Charlie Jetton and Richard Poels of Standard Transmission and Gear in Fort Worth, Texas. In lighter duty and moderate towing, the G56 transmission has been adequate. Hot shotters and other owners who do very heavy towing have experienced failures that are still not completely resolved. Conventional rebuilds help, but do not eliminate all problems for these owners.

Richard Poels of Standard Transmission explained that the G56 transmission often came with too little lubricant, and further that automatic transmission fluid may not be suitable under some driving conditions. A slightly “heavier” lubricant is better at the elevated temperatures that the transmission may experience towing or at higher ambient temperatures. They recommend that lubricants successful in the NV5600, such as Pennzoil Synchronesh, be used. My NV5600 did very well with Torco RTF (Issue 67, page 87) and it should be an excellent lubricant for the G56. Aluminum “grows” with heat at about three times the rate of cast iron, so endplay clearances can become excessive at high transmission temperatures. High ambient temperatures and heavy towing both increase transmission heat; the unit is “trapped” in a floor tunnel

of the truck and gets limited airflow for cooling. Units run with the factory lube (ATF) come in to Standard with browned bearings from lubricant degradation.

Richard Poels took me through the procedures for correctly rebuilding a G56 six-speed, aluminum-cased transmission. Standard Transmission stresses cleanliness and goes to extremes to ensure the parts and housing are clean. As with most manual transmissions, the gearbox does not have a filter, so any grit, metallic dust, or pieces will circulate and cause more damage. For clean-up, they use both solvent washers and a hot tank. They use a special assembly lube, with high pressure additives.

The main drive bearing at the front of the case (the input shaft bearing) is prone to failure. If you hear a transmission noise, get it fixed immediately before the main case is ruined. Virtually every G56 that comes in for rebuilding has large endplay on the input shaft. The rear bearings also can fail. The spot welded shifter forks (photo 71-17) may break at the weld. Standard re-welds them inside and outside. Due to case flex and stretch, Standard often has to add 0.008" to 0.011" more shim to reduce endplay. The stock shim is generally 0.055" thick. In contrast, the cluster shaft usually takes the same shim, or at most 0.001" to 0.002" thicker shimming.



**71-17** Heavy stamped steel shift fork with welds that are prone to failure.

Standard often finds evidence of misalignment of the mainshaft gears versus the cluster gear, shown here on an input gear (photo 71-18). Broken gear teeth can result (photo 71-19). Wear patterns indicate that the teeth are spreading the transmission case, causing wobble in the input gear, and gear teeth are wearing closer to the edges of the teeth. Heavy loads then cause them to break.



**71-18** Input with wear indicating misalignment of gears.

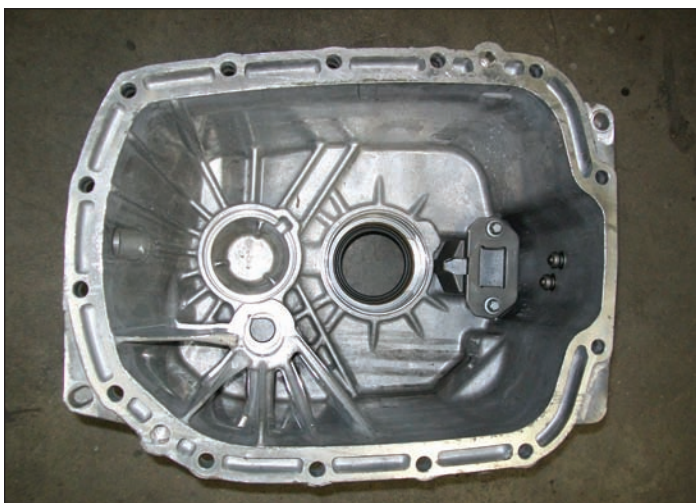


**71-19** Input and cluster with broken teeth caused by poor alignment and heavy loading.

The stock transmission case is two-piece, split crosswise just behind the shifter tower area (photo 71-20). Inside, the front of the case can be seen to include supports for all internal components. The inside view of the rear housing shows corresponding bearing and shaft mounting supports (photo 71-22). Owners have tried to repair cracked cases with poor success. This one was warped to 0.070" out of "square" by welding (photo 71-23).



71-20 G56 two-piece transmission case.



71-22 Rear half of G56 case viewed from the split at mid-case.

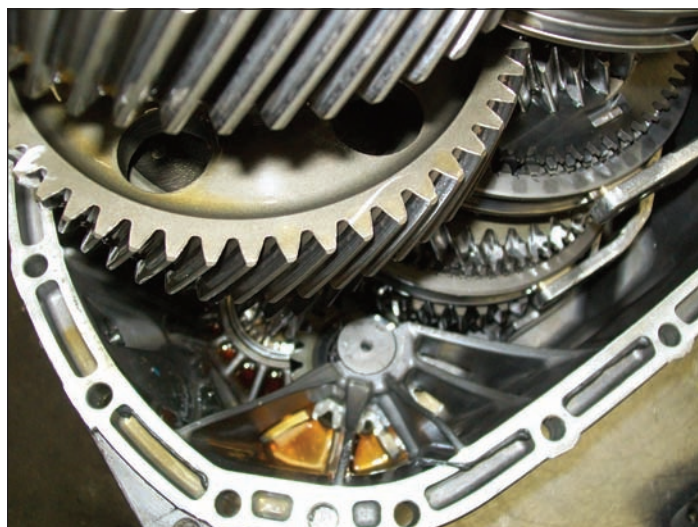


71-23 Welded but distorted G56 case at bell housing area.

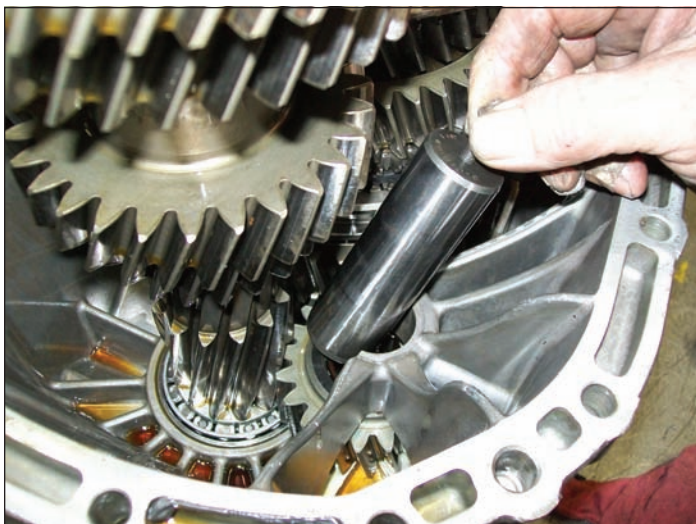
After splitting the case, the internal components remain in the rear case half (photo 71-24). A close-up view shows that the reverse idler gear prevents removal of the gear sets (photo 71-25). The secret to disassembly is to thread a metric bolt (M6 x 1.0 thread) into the end of the shaft, and remove the shaft (photo 71-26). Then, push the gear out of the way and separate the cluster and mainshaft (photo 71-27).



71-24 Rear half of the case with mainshaft and cluster assemblies.



71-25 Close up view of reverse idler gear in rear half of case.

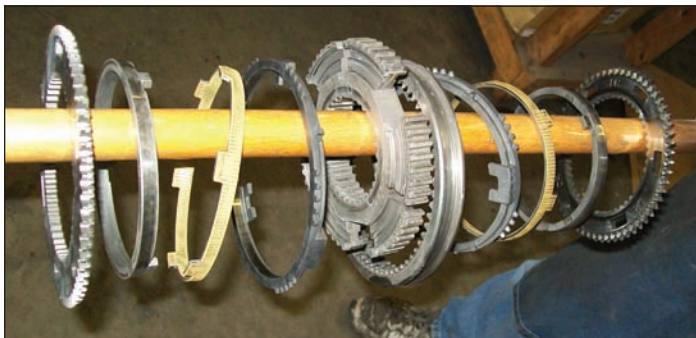


**71-26 Removal of idler gear shaft.**



**71-27 Separation of cluster and mainshaft assemblies after moving reverse idler gear out of the way.**

This transmission is a German design, but manufactured in Brazil. Currently, parts have to be purchased from Dodge at high prices. For example, each synchronizer assembly (photo 71-28) is a complete set for a pair of gears (1-2; 3-4; 5-6) and costs as much as \$740. The input shaft/gear costs \$750; the cluster gear, \$1385; mainshaft, \$474; sixth gear, \$450.



**71-28 Synchronizer assembly for one pair of gears (1-2, etc.)**

Standard has seen electrolytic pitting of gear teeth (photo 71-29) similar to that seen in automatic transmissions which also have aluminum cases. An extra ground strap such as is sometimes added to automatics may be the cure for this issue. The damage is seen on the leading drive side and edge of cluster and main gear teeth, presumably from an electric field being generated.



**71-29 Electrolytic pitting of gear teeth.**

It appears that the transmission case is irreversibly spreading lengthwise more at the mainshaft (top) than at the cluster. The mainshaft being two-piece, with an input gear separate from the rest of the mainshaft, contributes to the forces spreading the case, and brings about the excessive endplay seen in the mainshaft and sloppy sideplay felt when wiggling an input shaft side to side. This is a buckling or distortion and not merely dimensional growth with heat, although that growth is no doubt involved also. I brought up the idea of building a "girdle," possibly with load bolts to the top of the case, and Standard is looking into this modification in an effort to strengthen the G56 case which appears to be rather thin, inadequately reinforced at the top, and further weakened by being split cross-wise.

In summary, the G56 has proved itself as a fairly good transmission but several upgrades are worth considering: more and better lubricant; preventive teardown and rebuild before catastrophic failure; downshifting to avoid heavy towing at low rpm; and changing the clutch periodically, making sure to replace the pilot bearing as well. This transmission does not seem well suited to heavy towing beyond manufacturer's recommendations.

#### **Standard Transmission and Gear**

1000 NE 29<sup>th</sup> Street  
Fort Worth, TX 76106  
1-800-STD-TRAN

**Joe Donnelly**  
TDR Writer

# Ram Automatic Transmissions

*Over the years the tech guys at Geno's Garage have grown weary of answering the same questions about automatic transmissions. They asked if I could help tie many of the topics together in one central document. My comment, "That sounds like something that should go into the 'Perfect Collection'." Collectively here is our attempt to cover the subject of automatic transmissions from 1994-2014.*

## RAM AUTOMATIC TRANSMISSIONS 1994-2014

by Robert Patton

How do I start this article?

How about a story to captivate your interest? Travel back with me to the spring of 2008. Yes, spring of 2008, we all started that year with an uneasy feeling. Diesel fuel was experiencing a meteoric rise to the \$5 zone. At that time I was busy with a two-part series (Issue 61 and 62) titled "It's About the (fuel) Economy, Stupid!" The series was unique in that we asked for vendor responses to help the audience understand the cause and effect, as well as payback, for modifications that could be done to the 1989 to 2007 Cummins engines.

Later in the year 2008, we were collectively trying to pick up the pieces from a market collapse. It did not take long for the diesel fuel price to drop in half. For many of us our net worth/investments also dropped in half.

Oops, I'm starting to lose my focus. Back to the story.

I mentioned that I had help from outside vendors in writing the "Fuel Economy, Stupid" article. And, should you want to review the text, it can also be found in the [Turbo Diesel Buyer's Guide](#) (TDBG), pages 102-115.

In my preparation for this article I had a chance to re-read the text. Even for this seasoned veteran it was a valuable reminder of how the cost/benefit/payback equation works. (Or, doesn't work?) A tip of the hat to the contributing vendors and TDR writers that give you valuable data rather than contrived results.

The concept of, and my success with, using vendor input to help you with the fuel economy story led me to draft an article about automatic transmissions. The basis for the article was a series of questions by TDR member Nic Crowhurst. (Nic, I hope you still receive the TDR.) I took Nic's questions and thought I would try the "vendor input" thing again. So the questionnaire was handed out to vendors at the 2008 SEMA show.

No response. Ditto 2009 and 2010. The article was shelved. I was disappointed.

In my review of this old file folder I had a bright idea: just write my responses to Nic's questions and double-check my work with the folks at Chrysler. Ram/Chrysler's Eric Mayne, media contact for Powertrain Engineering, agreed that this question/response/review sounded like a good idea. Eric would also provide help with a look at the latest-and-greatest Aisin AS69RC transmission.

So, this story will have ten parts to it;

- Let's Talk About Years '94-'07 (163-166)
- Vintage '94-'04 Lock/Unlock (166)
- '94-'98 TPS Quirk (167-168)
- More Torque Converter Lock/Unlock (154-155)
- Exhaust Brake Mystery Switch (171-172)
- Questions About The '07.5-Current 68RFE (173)
- Background On The '07-'12 Aisin 68RC (174)
- A Look At The '13-Current Aisin 69RC (175-177)
- How Hot Is Hot: Transmission Fluid Temperatures (178-179)
- Back To The Basics: Change All The Fluid (180-181)

## Let's Talk About Years '94-'07

Enough of the story-behind-the-story. Here is the correspondence from Nic Crowhurst that has finally resulted in a Ram Automatic Transmission article. In early 2008 Nic wrote:

*First I wish to thank the TDR members for the great assistance that the TDR magazine and forum have given me over the past eight years of owning my '98, 12-valve Quad Cab truck. The ownership experience would have been far less pleasurable without your help. I am a UK citizen, but spend the winters in the US keeping in touch with the one half of my family which lives in Minnesota.*

*I have long had an idea for a TDR magazine article. How about, "Your basic auto transmission questions answered here," or "Auto 101." I've spent 45 years as a shadetree mechanic in the UK, but solely on manual gearbox vehicles. I've rebuilt engines and gearboxes, but the auto tranny is a new box of tricks, and, even having studied the schematics of the 47RE auto, I still have a great amount of ignorance in the simplest issues. Here are a few of my queries, which mainly relate to keeping the transmission operating for as many miles as possible, with the highest reliability.*

Nic then followed with seven questions that likely parallel inquiries that you've wanted to ask but did not have the forum to do so.

So, the following are Nic's questions, my answer (used only as a starting point for discussion) and the responses from the Ram/Chrysler engineers.

**1.** *Waiting at stop lights, my inclination is to shift to Park. If I leave it in Drive, will this shorten the life of the transmission, or will it just generate heat, which might be a good or a bad thing? (I have a transmission temperature gauge on the output line, and I keep below 200°.)*

**Editor:** Nic, the very small amount of heat generated by the stop light or fast food drive-thru does not warrant the extra stress put on the universal joints as you shift the transmission in and out of Park. Additionally, the move to Park makes your truck vulnerable to an accident as your reaction time is compromised by having to make a shift into Drive.

There is only one situation I can foresee where shifting from Drive could be beneficial. If you're stuck in a slow moving traffic jam, it could be beneficial to jockey between Drive and Neutral. With the truck in Neutral there is fluid flow to the automatic transmission cooler. Watch your temperature gauge and let it tell you whether the Neutral shift-in-traffic is a good technique. And, remember, with the '89-'07 Dodge truck transmissions, the shift to Park stops the flow of fluid to the transmission cooler, hence to check your truck's ATF level the Dodge truck must be in Neutral. Your Owner's Manual will confirm this on these older trucks. Note: In '07.5 and newer trucks, 68RFE or Aisin, you can check the fluid in Park or Neutral.

**Ram/Chrysler:** What's important is the transmission sump temperature. Normally we like to keep the sump temperature below 220°F. Torque converter out temps should be below 270°F. Keeping the transmission in drive will pose no durability problems. Excess shifting will increase fatigue on rear clutch components, so it is not recommended that you cycle in and out of Drive at a traffic light.

**2.** *I have altered the overdrive switching so that default is "no overdrive (OD)," and I have to select OD manually. I prefer this, particularly when towing, to avoid lugging. I tend to accelerate in 3rd up to perhaps 50mph, and only then drop into OD. Is this reasonable?*

**Editor:** Reasonable, with your trailer in tow, yes. However, I can imagine that the majority of Turbo Diesel owners put 'er in Drive and go. That's what I do.

Practical for around town? No. Join the ranks of the millions of other owners of vehicles with automatic transmissions, drop it in Drive and let it go.

Reading between the lines, I think your real concern is lugging your '98 12-valve engine and/or the stress the transmission's torque converter lock-up disc must endure with the OD lock-up at a slow speed. I have a "don't worry, be happy" attitude, and in my 20 years of experience I have yet to have an automatic transmission problem. My truck and trailer are below the GCWR and the transmission is not "overpowered" by a big horsepower/modified engine.

Bottom line: the engine will let you know if it is lugging too much by its inability to increase road speed as the boost does not rise and the EGT starts to climb. This lugging condition will start below 1600rpm.

Regarding stress to the transmission's lock-up disc: Just like a manual transmission's friction disc, if you overpower and slip the disc then it is time for a rebuild. I like the "accelerate in 3rd up to 50mph and then shift into OD" technique that you use when towing.

**Ram/Chrysler:** When towing, it is wise to not shift to OD until 50mph (depending on axle ratio) or when engine speeds in OD are less than 1600rpm. This will reduce high engine torsionals into the transmission to improve fatigue life of the input, torque converter damper and clutch. This also prevents clutch hub brinelling and other shaft fatigue. When not towing, it is completely acceptable to shift into drive and operate normally.

**3.** *When towing, the Dodge manual says not to use OD. Also, my 12-valve engine defuels at about 2600rpm. In theory, then, the truck should not pull a trailer over about 65mph. If I'm towing my 6500 pound Airstream travel trailer on a level highway, with no strong headwind, am I truly risking my clutches by going into OD, and back to third on the slightest grade? I have a BD TorqueLoc, which increases the line pressure at low rpms. I get 13mpg towing in 3rd, and 15mpg in OD, with far less noise to disturb the passengers. Speed is about 63mph.*

**Editor:** I don't have the patience to switch switches. I don't have the patience to drive at 65mph. You have a light load and the benefit of the aftermarket torque-lock. I do not think you have any risk of slipping the lock-up clutches with the use of OD at all times.

The mention of the Dodge Owner's Manual and "non-use" of OD when towing concerned me. So I went to my '07.5 manual to re-educate myself (remember, I shift into Drive and go). The instructions:

When to Lock Out Overdrive:

When driving in hilly areas, towing a trailer, carrying a heavy load, etc., and frequent 4-3-4 transmission shifting occurs, press the "TOW/HAUL" button. This will improve performance and reduce the potential for transmission overheating or failure due to excessive shifting.

From the '97 Owner's Manual:

When to Lock Out Overdrive:

Vehicles equipped with a 4-speed automatic transmission may exhibit shifts into and out of Overdrive or a lower gear, when driving in hilly areas, when heavily loaded or when towing into heavy winds.

When this condition occurs, it is recommended that you turn the Overdrive off or shift into a lower gear (Drive to 2nd) to prevent excessive transmission wear and/or overheating, and to provide better engine braking.

So, in my review of both Owner's Manuals my interpretation on shifting out of overdrive is that it is only necessary if conditions dictate. Let 'er rip into overdrive and enjoy the fuel mileage.

To address the mention of overheating that was in both Owner's Manuals, one has to remember that the heat is caused by the unlocked operation of the torque converter. When unlocked, the torque converter is shearing the fluid and making heat. With the torque converter locked up in 3rd or OD there is positive engagement and heat is minimized.

As an example of "unlocked/shearing the fluid," think of sitting in stop-and-go-traffic with the trailer in tow. There is minimal air flow over the transmission cooler, and the transmission is in lower gears shearing the fluid. Ditto in a campground area trying to spot your a trailer. Ditto under 45mph in urban/traffic situations.

**Ram/Chrysler:** If hunting or frequent shifting occurs between 3<sup>rd</sup> and 4<sup>th</sup>, then shift to 3<sup>rd</sup> gear, or if engine lugging occurs below 1600 rpm.

*4. Although I change the fluid and filter correctly, I have avoided adjusting the bands. I feel that, even with the information from my full Chrysler workshop manual, this is a risky procedure when the transmission is always shifting correctly. I have read contrary views. One is that the band adjustments can be ignored on a 47RE, and the other is that regular band adjustment is important. What do the TDR gurus recommend?*

**Editor:** The lazy editor says, "If it ain't broke don't fix it."

**Ram/Chrysler:** If it ain't broke don't fix it (An RE transmission engineer from the past echoes this advice.) The kickdown band normally had negligible wear during durability testing.

*5. I'd rather replace a problem before it leaves me stranded at the roadside. Am I likely to get warning of a failing transmission? Mine has 150,000 miles and it operates perfectly. The torque converter seems loose, but I understand this is to protect the transmission from the Cummins torque. What would be the warning signs? More TC slippage?*

**Editor:** The "warning signs of a failing transmission...more TC slippage?"

First off, if you change the transmission fluid often, you'll notice magnetic particles and friction disc material in the transmission drain pan. The fluid will be a contaminated/dark color.

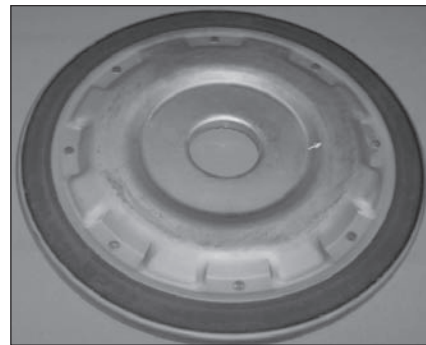
To address a specific failure, the warning sign would be a rise in engine rpm as the torque converter's friction disc (just like the friction disc on a manual transmission clutch wear out) and fluid pressure are not enough to keep the transmission locked-up. This worn out/non-lock condition can also show up as a shudder when the vehicle reaches the lock-up speed of 50mph. It will feel like the truck is traveling over those emergency lane rumble strips. How long the truck can be operated in this obvious need-of-repair condition depends on the load being pulled. Like a slipping clutch in a manual transmission, the lock-up (or lack thereof) problem will happen all at once.

To further this discussion, I pulled out the Service Manual for the 2004 Turbo Diesel. Would you believe that there are nine pages of

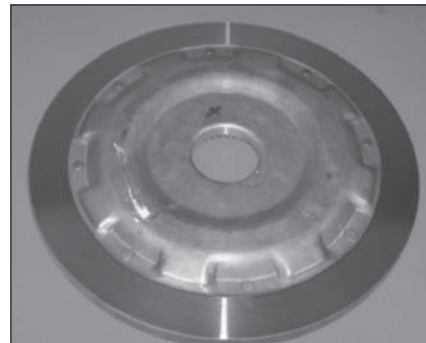
condition/possible cause/correction for the 48RE transmission? In the modern world of electronic, mechanical and hydraulic devices there is not an easy answer. Dodge factory service manuals are an excellent resource.

Finally, the photos below are from Sun Coast Transmissions. They were published back in Issue 45, August 2004. Imagine, if you will, the owner that has increased the engine's power/torque from 180/240 to 350/650. The weak link becomes the torque converter friction disc area of 32 square inches. Using the newfound power/torque, owners would overpower the friction surface and then cuss the transmission. Misguided frustration?

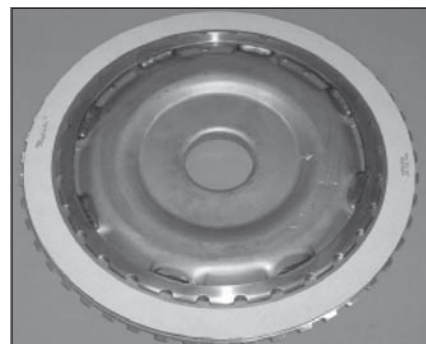
**Ram/Chrysler:** Agreed. Early signs of failure are either noise, slippage in lock-up gear, delayed/long shifts and higher-than-normal sump temperatures.



**OEM stock piston with 32 square inches of friction surface.**



**Sun Coast single disc piston upgraded to 50 square inches of friction surface.**



**Sun Coast multi-disc piston. This configuration provides 96 square inches of friction surface.**

**6.** *The shop manual describes a stall test for the torque converter. This seems a brutal procedure and, hence, I have avoided it as a means of assessing the torque converter/engine horsepower match. Should I be wary of this procedure?*

**Editor:** Nic, several years back we did a write-up on the stall test. As I went to update the article, my research involved the factory service manual(s) and Dodge's stall test procedure. I found mention of "Stall Test Analysis" in the service manuals up to year 1999. With a 15-year lapse, as well as many more pages covering the subsequent 47RE, 48RE and 68RFE transmissions, I am thinking that this test technique is no longer valid.

After the quote from the old service manuals, I am going to ask Chrysler to weigh-in with their responses. The old 1999 factory manual reads as follows:

**"Stall Speed Too High**

**"If the stall speed exceeds 1800-2300rpm by more than 200rpm, transmission clutch slippage is indicated.**

**Stall Speed Low**

Low stall speed with a properly tuned engine indicates a torque converter overrunning clutch problem. The condition should be confirmed by road testing before a converter replacement. A stall speed 250-350rpm below normal indicates the converter overrunning clutch is slipping. The vehicle also exhibits poor acceleration but operates normally once highway cruise speeds are reached. Torque converter replacement will be necessary.

**Stall Speed Normal but Acceleration Poor**

If stall speeds are normal (1800-2300rpm) but abnormal throttle opening is required for acceleration, or to maintain cruise speed, the converter overrunning clutch is seized. The torque converter will have to be replaced."

So (15 years later) does Chrysler recommend a stall speed test?

**Ram/Chrysler:** A high stall speed would either mean the rear clutch/overrunning clutch in the transmission is slipping or higher than normal engine performance is occurring. A low stall speed would mean poor engine output or a failed torque converter overrunning clutch (slipping). The reason for this is that the torque converter does not multiply torque but becomes a fluid coupling device with a slipping torque converter over running clutch. Normal stall speed, but poor vehicle performance would mean the torque converter overrunning clutch is seized.

**7.** *I am accustomed to hauling heavy loads, and we all know that at the beginning of a downhill, one should shift to a low gear to use engine braking. Hence, I was stunned to discover that my older truck with the 47RE unlocks the TC under these circumstances, and the truck can freewheel down the grade. I immediately had a BD exhaust brake and Auto-lock fitted to the truck. Was this a good idea?*

**Editor:** The downhill scenario you described and the "I am my own warranty station" mantra of TDR owners led us members/owners/users to develop the "torque converter mystery switch" so that we could use exhaust brakes with the '94-'07 automatic transmission equipped trucks.

Looking back, use of the lock-up switches and exhaust brakes was finally approved for model year '06 truck and newer. As we all know, the '07.5 engine's variable geometry turbocharger serves as an exhaust brake and the newer 68RFE and Aisin transmission are programmed to lock-up in the higher gears.

**Ram/Chrysler:** All Chrysler Group products meet or exceed all applicable safety standards. Accordingly, our customers have enjoyed millions of miles of reliable service.



**Do you want to know more about the use of an exhaust brake with an automatic transmission? It is covered in detail in the [Perfect Collection](#), page 4-18. This is a photo of author David Magnoli's exhaust brake that he discusses in the [Perfect Collection](#) article.**

**8.** *Fitting an exhaust brake to these transmissions ('94-'06 vintage) is a contentious issue. I like to use mine all the time, even when running empty. This suits my driving style, as I try to avoid using the foot brake unless coming to a stop. This gives the passengers a smooth ride, helps fuel economy, and prolongs brake life. However, am I risking wearing out the auto transmission clutches by always using the exhaust brake?*

**Editor:** Like a manual transmission, only when the clutches slip do you wear them out. Keep the converter clutches locked and you're not at risk.

**Ram/Chrysler:** We are unsure as to the amount of engine braking torque with these aftermarket systems.

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*Looking back, use of the lock-up switches and exhaust brakes was finally approved for model year '06 truck and newer.*

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## Conclusion '94-'07

Using TDR Member Nic Crowhurst's questions as items for discussion allowed us to cover the subject's high points. However, when I did the research to find the pictures to dramatize the lock-up disc used in the '94-'07 years transmissions (models 47RH thru 48RE), versus the lock-up disc used in those for the performance aftermarket transmissions, I was taken aback by the data that our membership group has covered.

So, these "Conclusion '94-'07" paragraphs will wrap-up the Nic Crowhurst questions, but it is only the tip-of-the-iceberg in terms of data that is available to help you correct a specific transmission problem.

This is where the good 'ole TDR indexes that were published each year are a great resource for the "print guys." These older magazines are in PDF format at our website. The indexes were published in Issue 41, 45, 49 (etc., just add 4), up until Issue 65. From 65 and newer, the magazines can be found in digital form and searched using keywords.

So, when you find your old '95 truck's transmission is hunting in out of overdrive (hint: throttle position sensor; the catastrophic hunting or shudder that was discussed in Crowhurst's question number 5, page 46; or could it be throttle return springs) or your '99 truck goes on the same "hunting" adventure (hint: throttle position sensor; the catastrophic hunting or shudder that was discussed in Crowhurst's question number 5, page 46 or could it be electrical interference from the alternator) you have tons of information available to help you troubleshoot the problem.

Likewise, in the Crowhurst Q&A we didn't discuss the bad reputation the early transmissions received due to failure of the transmission cooling lines. See page 161 for the discussion.

Okay, this concludes the '94-'07 section. Let's talk about the '07.5-current Chrysler 68RFE transmission.

***In the original TDR article that was published in Issue 84, the section on '94-'07 transmissions was concluded. However, since the majority of problems occur with these year model transmissions, it is appropriate to add some tips about the infamous "lock/unlock" problems that long-time owners have suffered through.***

***The following are tips that I've pulled from other TDR magazines as well as the Turbo Diesel Buyers Guide.***

***If yours is the 68RFE or newer Aisin transmission you can skip over to page 158 and continue with this article.***

## VINTAGE '94-'04 LOCK/UNLOCK

How do I stop the automatic transmission from unlocking when the truck is in overdrive or third gear?

Unfortunately there is not a "one size fits all" answer to this question. However, at Geno's we benefit from the millions of miles of knowledge from members of the Turbo Diesel Register magazine and from our own busted knuckle experiences.

Before we suggest some different part numbers and repair techniques we have to break this lock/unlock problem down into year models of the truck:

'94-'98 with a 12-valve engine

'98.5-'04 with the 24-valve engine

(VP44 injection with the '98.5-'02; HPCR with the '03-'04)

All year model trucks may benefit from a noise isolation product from BD Power, part number BD 1300030. Interference in the throttle position sensor circuits (APPS) on Dodge Cummins engines from '94-'04 will create false voltage readings in the APPS/TPS circuit and cause the lock-up torque converter to rapidly cycle on and off as you drive. This part removes the RF interference.

If yours is the '94-'98 with the good 'ole 12-valve engine you'll want to read the article "TPS Quirk" from our Issue 83 magazine. For your convenience that article is a part of this collection and is found on page 152-153.

If the noise isolation is not the problem, for '98.5-'04 owners the next step is to look at the accelerator pedal position sensor (APPS), also known as the throttle position sensor (TPS). The Geno's Garage replacement is an aftermarket item that is half the price of the factory unity. Our part number is TPS 98502.

You can read further about the lock/unlock problem in your TDR magazine(s). Related articles:

### Transmission Noise

Issue 70, page 28

Issue 69, page 30

Issue 62, page 25

Issue 54, page 38

Issue 53, page 10

### APPS

Issue 68, page 29

Issue 66, page 30

Issue 60, page 92

### Shift Problems

Issue 60, page 28

Further, as a part of this "Perfect Collection" article I have included several other lock/unlock stories as well as wiring diagrams for exhaust brake "mystery switches." See pages 154-157.

## '94-'98 TPS QUIRK

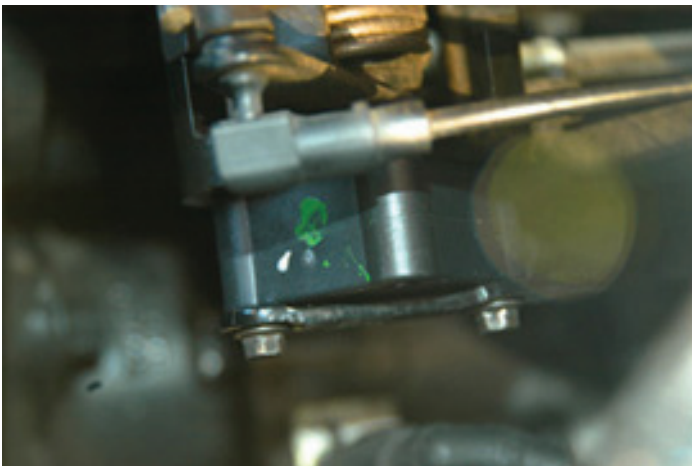
by Scott Dalglish

Recently, I was able to take care of some nagging quirks. I get bugged when little annoyances begin to multiply, and this one had been going on a little too long. The throttle position sensor (TPS) had began to show early signs of failure. I'd be driving along, minding my own business, and the truck would elect to downshift from fourth gear to third gear with no warning. (Other TPS "bad" symptoms can be no torque converter lockup or unscheduled locking and unlocking.) I had found a way to pedal around the downshift and get back into fourth gear, but it was beginning to really annoy me. So having time to replace the TPS was good.

Changing out a faulty TPS requires a voltmeter, 7mm socket, a paper clip (sharpened on one end) and good quality dielectric grease. The service manual outlines one process; I was taught a simpler method that I'd like to share with you.

The TPS is located on the driver's side of the P7100 injection pump and is attached by two 7mm bolts to the throttle linkage. There is a small plug at the base of the TPS in the four-o'clock position containing three wires. The wires are:

- Black – ground
- Orange/Dark Blue Stripe – signal
- Purple/White Stripe – 5-volt power



A small black box located to the front and side of the P7100 injection pump.

Testing the TPS is simple. I sharpened one end of a paperclip (a highly technical diagnostic tool) and inserted it into the center pin of the three-wire plug. Be sure it is far enough to make contact with the center pin connector. Install the plug back into the TPS, being careful not to break off the keeper on the side of the plug. To the paperclip signal lead I attached the positive connector of my voltmeter. Attach the negative connector to the negative pole on the battery.



A sharpened paper clip inserted into the center position of the connector.

I wanted to read the voltage present with the key in the on position to observe the increase and decrease of the voltage as the throttle is manually increased and decreased. Make note of the voltage. The service manual says to adjust the voltage between .8 to 1.2-volts at idle or in this case with the key on engine not running. My voltage read .864, which is the minimum, as stated in the service manual. I then observed the voltage as I slowly moved the throttle by hand from idle to wide-open throttle (WOT). This should be a smooth rise in voltage. If it jumps around, the TPS is defective and should be replaced. No surprise, Red Ryder's old TPS voltage was jumping around; time for a replacement. Geno's Garage is where I turned for the new TPS. The part number is 3930318 for the 12-valve version. The service is great and shipping solid.



My line voltage at idle (key on, engine not running) was .864 volts.

## The Installation

What has become common knowledge over the years is that it is better to set the volts at the higher range of the scale for better converter lock and shift points later in the rpm range rather than earlier. The voltage is adjusted by installing the TPS with the bolts snug and the paperclip in place so that a voltmeter can measure the voltage just as was done for testing. (Key in the on position, engine not running.) Slowly rotating the TPS will change the voltage. The TPS rotation is in very small increments: clockwise to reduce the voltage and counterclockwise to increase the voltage. It takes very little rotation to make a change in voltage. Set the voltage for the upper range (1.2-volts) and lock down the 7mm bolts and it's good to go.

## The Modification

However, there is a way to enhance the shift points. If I set the TPS at 1.8-volts, not only will I receive better shift points and lockup, but the torque converter will remain locked up when I remove my foot from the accelerator pedal. Not to worry, it will disengage if you apply the brake pedal or at lower speeds. This has all kinds of advantages in terms of enhancing the driving characteristics of the automatic to be more in line with that of a manual transmission. An example: If I remove my foot from the accelerator going downhill, the torque converter unlocks and I begin to freewheel. By modifying the TPS to obtain 1.8-volts, the torque converter remains locked until I either touch the brake or slow to a point where it unlocks. I found my modification would promote torque converter lockup in fourth gear at speeds approximately above 45mph and in third gear down to speeds approximately 30mph. It also works great with the exhaust brake engaged.

To make the modification I used a small screwdriver to remove the steel inserts from the two mounting holes by pushing them out.



Remove the two steel sleeves from the TPS.

Next, using a 3/16" round file, I carefully "slotted" the two mounting holes allowing for more counterclockwise rotation for increased voltage. Be careful not to file past the mounting hole supports in the switch housing. Mount the modified switch in place, remembering to apply a dab of dielectric silicon in the sensor's plug socket to promote good contact and eliminate moisture.



Using a 3/16" rat-tail file, I slotted the two mounting holes allowing for more rotation of the switch.

Using the same procedure I used to test the TPS, I now set the new modified TPS to 1.8-volts.



I now have 1.8 volts at the "idle" position of the TPS.

After locking down the 7 mm bolts I rechecked the idle voltage and manually moved the throttle to WOT, checking the voltage was smooth as it increases and decreases.



Manually moving the TPS from idle to WOT the voltage displays smoothly to 4 volts.

After road testing, the new, modified TPS works as advertised! This is one of those simple TDR shadetree modifications that make a big difference in the drivability of Turbo Diesels with automatic transmissions and is another benefit of being a TDR member.

## MORE TORQUE CONVERTER INTERMITTENT LOCK/UNLOCK

At 37 to 40-mph in third gear and at 52 to 55-mph in fourth gear the transmission in my '01 Turbo Diesel (351,000 miles) will shift in and out of torque converter lockup repeatedly. I've tried the "fixes" suggested by members, but obviously I am missing something. The alternator wires have been wrapped for years. I thought it was a defective ground at the battery since the cable has a non-factory end that was loose which I repaired. I serviced the transmission and found no problems. I replaced the accelerator pedal position sensor (APPS) assembly which didn't solve the problem. I have run out of ideas to remedy my problem.

**hammersley, Camas, WA**

Unwrap the alternator wires, cut the alternator ground wire and alternator charge wires out of the existing harness, and reroute them separately and away from each other. Route the alternator ground wire along the firewall to the four-way split in the harness and the alternator charge wire over the radiator support. Rerouting those two wires has the highest success rate of any fix, so you might as well start with something that works.

**cerberusiam, McDonough, GA**

I will try your solution. Do you have any photos of the wire rerouting modification?

**hammersley, Camas, WA**

My son did the modification. He actually pulled the ground wire completely out of the harness and extended it so he could route it along the firewall instead of in the engine control module/powertrain control module (ECM/PCM) harness.

He routed the charge wire from the alternator in the plastic conduit across the top of the radiator and back to the original termination point by the power distribution center (PDC).

**cerberusiam, McDonough, GA**

After nothing else worked, rerouting the alternator charge wire has solved the problem. Why, after 360,000 miles, did the torque converter lock/unlock problem suddenly develop? Years ago, I had the aluminum foil shielding wrapped on the harness near the alternator and no problems. What changed to make the rerouting necessary?

**hammersley, Camas, WA**

Deterioration of the shielding in the wire and in the alternator is the usual culprit. The frequency changed just enough to set up a different type of noise that the shielding could not filter. As age deteriorates the PCM's ability to filter specifically stray noise, it begins to make more of an impact.

Unfortunately, the electronics deteriorate to the point where they may not work and the truck may become unusable. Add on filters and tin foil will not stop the problem when the frequency changes enough to impact the PCM as it ages. The ground wire is the usual culprit, but as you have discovered, the alternator charge wire can "dirty things up" also. I'm glad it worked for you.

**cerberusiam, McDonough, GA**

From my testing this weekend, it appears that the torque converter lock/unlock issue on my '01 Turbo Diesel 3500 may be solved. I will know for sure in about ten days when I tow my fifth-wheel trailer to the mountains of New Mexico.

I received many suggestions on how to correct the torque converter lock/unlock issue and followed up on all of them. Check the battery cables first!



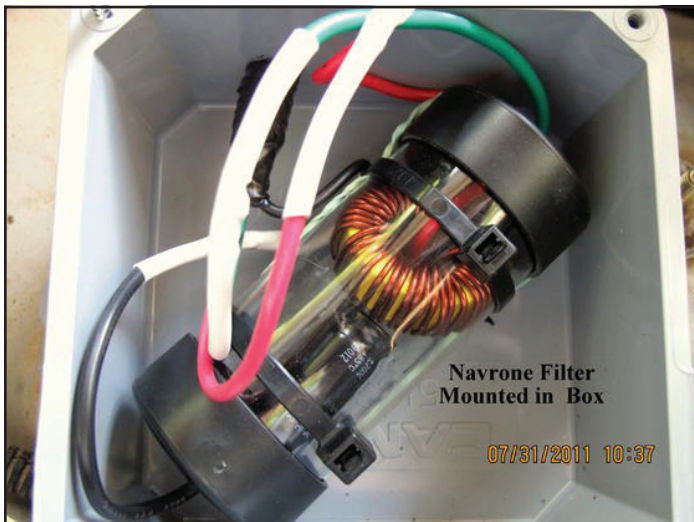
I followed the advice of TDR member "cerberusiam" and separated the alternator ground and charge wires from the rest of the wire harness. I re-routed the two wires and cleaned all the ground connections.

I also installed a Navrone noise suppression filter Model N-25 by Navone Engineering at (<http://www.davidnavone.com/cart.asp?24&cat=2> or 800-669-6139) as seen in the photos which may be helpful to other members who might want to use this electrical noise filter. I rerouted the alternator charge line and ground at the same time. After completion of the project, I have driven the truck on the highway and could not reproduce the torque converter unlock/lock issue.





Photos of final installation with air cleaner housing re-installed.



Silver Ratler, Lubbock, TX

*Editor's Note: For more information on the common intermittent torque converter unlock/lock problem and suggested repairs, see Issue 73, page 32; Issue 71, page 35; Issue 70, page 30; Issue 69, page 30; Issue 62, page 25; Issue 53, pages 10 and 38. One or a combination of suggested repairs appear to have been successful.*

## EXHAUST BRAKE MYSTERY SWITCH

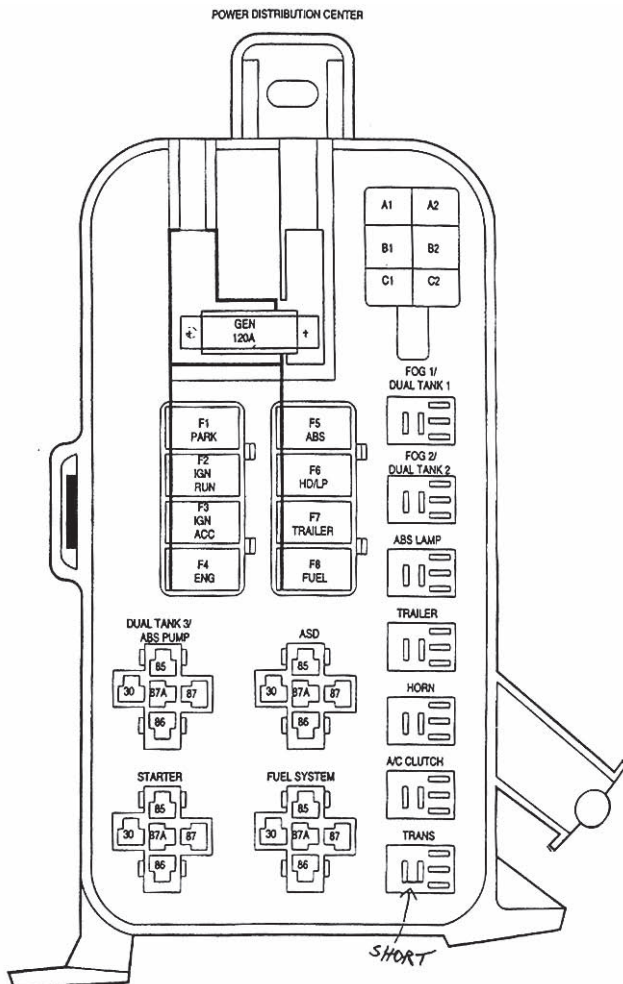
### Torque Converter Lockup Switch for '96-'98 Ram

The following diagram is supplied at no cost or obligation by TST Products. Note that use of this method of lockup may be hard on vehicle drivetrain and may void vehicle drivetrain warranty. Use makes vehicle drive like a manual transmission in 4th gear such that vehicle may/will stall at low speeds/stops if lockup is not disconnected.

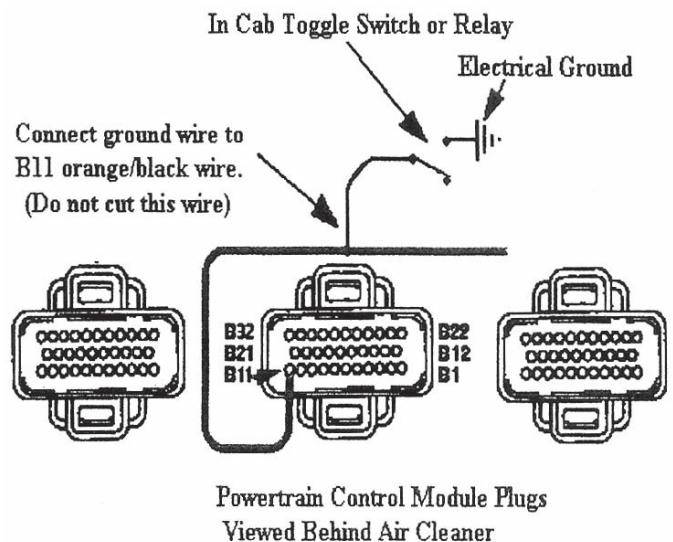
1. Install jumper wire in place of the trans relay in the Power Distribution Center (black box behind driver side battery) as shown in diagram below. This jumper wire will supply 12 volt positive to the transmission torque converter clutch solenoid. This jumper will be electrically hot thus it should be installed so as not to short against ground.

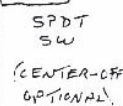
2. Install ground wire from the B11 orange wire with black stripe to a switch or relay such that the ground source can be turned on and off. The B11 wire is located in the middle computer connector located on the firewall behind the air cleaner.

Driver must ground the B11 wire, have gear selector in Drive, and be moving fast enough to be in 2nd gear before the torque converter clutch will engage. Transmission will shift from 2nd to 3rd, and 3rd to 4th (unless Overdrive is off) with the torque converter clutch locked. Once in 4th, the transmission will not downshift unless the ground source is interrupted, i.e. the switch is turned off.



**Add Jumper Wire**  
**Do NOT Reinstall Relay**  
**Power Distribution Center**  
**Next to Driver Side Battery**



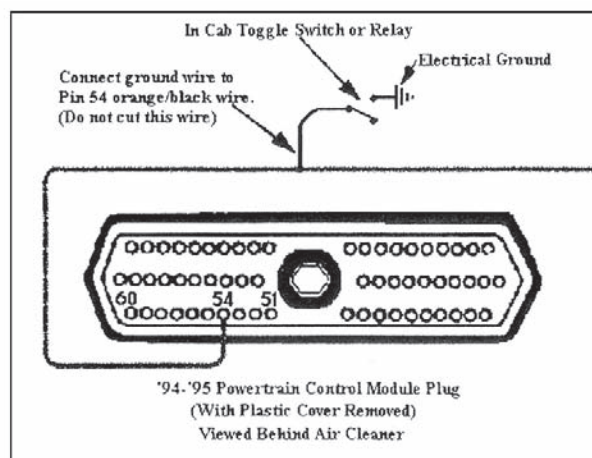


## Torque Converter Lockup Switch for '94-'95 Ram

The following diagram is supplied at no cost or obligation by TST Products. Note that use of this method of lockup may be hard on vehicle drivetrain and may void vehicle drivetrain warranty. Use makes vehicle drive like a manual transmission in 4th gear such that vehicle may/will stall at low speeds/stops if lockup is not disconnected.

Install ground wire from the pin 54 orange wire with black stripe to a switch or relay such that the ground source can be turned on and off. The pin 54 orange wire with black stripe is located in computer connector located on the firewall behind the air cleaner.

Driver must ground the pin 54 wire, have gear selector in Drive, and be moving fast enough to be in 2nd gear before the torque converter clutch will engage. Transmission will shift from 2nd to 3rd, and 3rd to 4th (unless Overdrive is off) with the torque converter clutch locked. Once in 4th, the transmission will not downshift unless the ground source is interrupted, i.e. the switch is turned off.



## 68RFE QUESTIONS

### Chrysler 68RFE Background

This transmission was introduced in '07.5 with the implementation of the 6.7-liter Cummins engine as a mid-model year product for the consumer 2500/3500 market. The initial engine ratings were 350hp/650torque.

The gear ratio comparison:

|                     | 1    | 2    | 3    | 4    | 5   | 6   |
|---------------------|------|------|------|------|-----|-----|
| '03.5-'07 48RE      | 2.45 | 1.45 | 1.0  | .69  |     |     |
| '07.5-current 68RFE | 3.23 | 1.84 | 1.41 | 1.00 | .82 | .63 |

I looked through the Turbo Diesel Register's (TDR) Buyer's Guide for any changes to the horsepower/torque ratings for the 68RFE. There was a revision in April of 2011 with an optional 3500 truck "Max Tow" package that gave the customer 350hp/800torque. This number was revised for the model year 2013 and the Ram 2500 truck with a rating of 370hp/800torque. It continues in the 2500 truck for the 2014 model year with the same numbers. (In 2013 the 3500 truck is paired with the new Aisin automatic.)

For those of you that want to do some in-depth research on the 68RFE, we were fortunate to have the factory folks weigh-in with an "Ask the Engineer" question and answer discussion that was printed in November 2007, Issue 58, pages 46-47.

There was another "Ask the Engineer" Q&A that we did when the Fourth Generation truck was introduced, in May 2010, Issue 68, pages 42-48. In this article the focus was the new truck chassis (remember, the engine and transmission were carry-overs from '07.5). The section that was specific to the 68RFE was on page 47.

For this issue I submitted a handful of questions to Ram/Chrysler. And, while I could ask them to elaborate, there is nothing wrong with the to-the-point answers that I received. This transmission brings to mind the "Maytag Repair Man," whereby there just isn't anything to discuss. The transmission is that good.

1. Tell us about the success of the 68RFE. *The 68RFE transmission has been a very good and durable transmission often going over 300K miles without issues.*
  - a. Was its first and only use with Ram 2500 and 3500 trucks? *Yes and currently that's the case.*
  - b. Engineering hurdles? *Not many. Designed right from Day One. Very robust geartrain and uses 545/65RFE valve body, solenoid and controls.*
  - c. Engineering stories? *Nothing but positive feedback from the field.*
  - d. In the truck since '07.5. Units sold per year? *This segment accounts for approximately one-third of our truck sales.*
  - e. Warranty response? *Good*
2. Tell us about yearly updates to the 68RFE. *Only a few major changes. First was to anodize valve body to reduce valve bore wear in 10MY. The OD solenoid was removed in 11MY and just the MS solenoid was used to control the OD clutch.*
3. Future plans for the 68RFE, just 2500 truck applications? *Can't comment on future plans.*

## AISIN AS68 AND AS69 QUESTIONS

### Aisin Background

The Aisin transmission was first introduced in the spring of '06 with its first application being the '07 model year in the 3500 Chassis Cab trucks (Aisin model AS68). Later in '08, the AS68 transmission was used when the 4500/5500 trucks were introduced. Initial engine ratings were 305hp/610torque. The AS68 remained in Chassis/Cab trucks with this rating until '12.

In '13 the Chassis Cab 4500/5500 was released with a 325hp/750torque rating and the new Aisin AS69. The consumer 3500 truck was released in '13 with 385hp/850torque and the new Aisin AS69.

Like the brief Q&A answers that were printed in the preceeding "68RFE Questions," the Aisin responses were to the point. And like the 68RFE, Aisin's AS68 has proven to be another "Maytag Repair Man" type unit for Chrysler.

So, the following are the quickie responses followed by an indepth article by Christopher Sawyer, Aisin Powertrain PR, that details the changes from the '07-'12 AS68 model to the new-for-2013 AS69. Enjoy.

1. Background on Aisin. *They are an outstanding Automatic Transmission company supplying transmissions to all of Toyota as well as many other OEM manufacturers. Chrysler used a smaller Aisin transmission on the 1987-2001 Jeep Cherokee.*
2. Background on Aisin and Chrysler. *We have had a long history together and have had good experiences on both sides.*
3. Background on Aisin and Ram HD trucks. *We needed a transmission with a power take-off (PTO) for the chassis cab models and Aisin provided that niche.*
4. Tell us about the success of the first Aisin, the AS68RC. *Good durability and customer acceptance in the commercial markets.*
  - a. Was it (the AS68) first used with Ram? *AS68RC was first used in the RAM chassis cab vehicles 4500/5500.*
  - b. Engineering hurdles? *Cummins/Aisin interface issues – normal for a transmission integration project.*
  - c. Engineering stories? *Business as usual.*
  - d. Warranty response. *Normal levels of warranty at extended mileage for this transmission.*
5. Tell us about the new AS69. Changes? *Bigger torque converter, centerline components and clutches. Valve body has pressure switches removed.*
  - a. Larger torque converter – 310mm to 322mm.
  - b. New center line shaft. *Input shaft diameter increased from 25.9mm to 30.2mm.*
  - c. New planetary gear sets. *Yes, wider and more planetary gears for more torque capacity.*
  - d. New clutch pack. *More friction discs with higher coefficient of friction for more static capacity.*
  - e. New valve body. *Pressure switches removed for added robustness; control system changed to implement model based controls.*
  - f. New pump. *New pump with higher capacity for improved cooler flow.*
  - g. New bell housing/main case. *Same length as AS68RC but has a bigger extension/transfer case bolt pattern for increased stiffness and output shaft pitch diameter increased from 36.25mm to 46.76mm.*

See technical write-up by Christopher Sawyer, pages 158-160.
  - h. Internal ratios are the same? *Yes, the same as AS68RC.*

## A LOOK AT THE NEW AISIN AS69RC

by Christopher A. Sawyer

"We are what allows the Ram pickup owner to tow 30,000 pounds, and increase the vehicle's gross combined weight rating (GCWR) from 26,000 to 37,600 pounds," says Tom Brown, General Manager, Drivetrain Engineering, Aisin Technical Center of America. It is Aisin's job to manage the 850 ft-lbs of torque produced by the high-output 6.7-liter Cummins turbo-diesel found under the hood of the Ram 3500 Heavy Duty pickup and its 3500, 4500, and 5500 Chassis Cab cousins. Even though the highest torque numbers and heaviest GCWR are found in the 3500 pickup, the Aisin team factored in the duty cycle seen in commercial use so that the transmission, which Chrysler calls the AS69RC, could do double duty.

Since 2007, when Chrysler got back into the diesel Chassis Cab market, Aisin has provided the automatic transmission. This began with the Aisin AS68RC. However, because the pickup and Chassis Cab share sheetmetal, the Aisin transmission—which is slightly larger than Chrysler's in-house 68RFE transmission design—could be used in both.

The success of the AS68RC caught the eye of other automakers. One in particular asked Aisin to develop a unit that could handle even more torque than the Cummins engine produced at the time. Engineers began working on a new gearbox based on the power flow of the AS68 that would retain that unit's six forward speeds and general design. However, the potential customer decided not to pursue that market segment before the new transmission could progress fully through the development phase. That's when Chrysler came knocking. Competition in the heavy-duty pickup market was heating up, and the folks at Ram wanted to substantially increase the Ram HD pickup's torque and towing capacity. "Fortunately," says Brown, "we had already started down the road toward a transmission that was capable of the numbers they were talking about."

With the basic design set, the two companies sat down to work out a plan. The rated torque output of the planned Cummins engine was 240 ft-lbs more than the previous Chassis Cab engine, bringing with it the Ram HD pickup's GCWR and trailer towing capacity. Despite the rise, however, there would be no increase in the size of the transmission tunnel. The new transmission would have to fit in the same space as the AS68.

To increase the anxiety level just a bit more, the agreement between Aisin and Chrysler wasn't signed until early 2011. The new Ram 3500 HD was scheduled to go into production in December of 2012, and Aisin had to begin shipping transmissions by late November. If that wasn't enough, the AS69RC would be built in America and, thus, begin a process whereby the company shifted from importing completed transmissions from Japan to building and assembling them in North America.

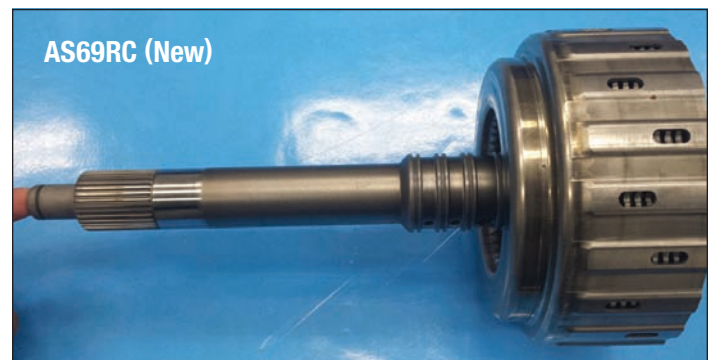
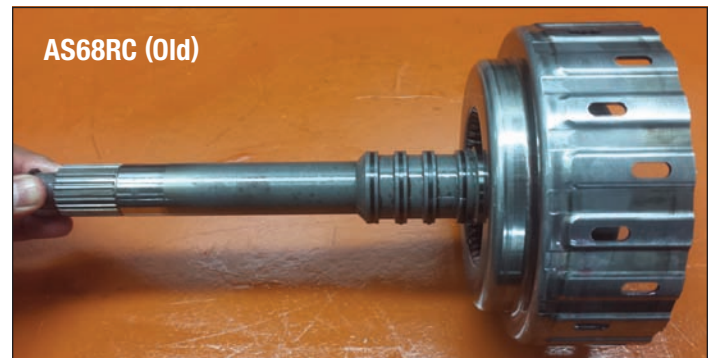
Assembly takes place at the Aisin Drivetrain Incorporated (ADI) plant in Crothersville, Indiana, using a transmission case sourced from the Aisin Automotive Casting plant in London, Kentucky, and an electronic control unit from Aisin Electronics' Marion, Illinois, facility. "The assembly line was first installed in our production engineering facility in Japan," says Nehal Rahim, Senior Engineer, Drivetrain Engineering, Aisin Technical Center of America, "and the people

who were to build the transmission in Indiana were flown there to build the first transmissions." All of the test prototypes were built on the same line as well. "This made development tricky as we had to bank a lot of parts to hold us over while the line was down," says Rahim. "If there was a design change, we had to wait until the line was back up before we could make new parts." To guarantee success, the line was validated in Japan, and again when it was reassembled in Indiana. Chrysler Supplier Development engineers regularly visited ADI during the line trials. The line passed muster without a hitch, and most—but not all—of the Japanese production engineers assigned to get the line through this process have since returned home. A few remain to iron out any troubles that might arise as the production volume increases.

Building from a proven base helped greatly, as did the multi-use nature of the transmission, and Aisin's global outlook. According to Rahim, "We have a family of gasoline and diesel six-speed commercial transmissions in Japan, each with a similar power flow and geartrain. The core design is done there, and the application engineers decide what changes are necessary for its use here based on OEM requirements, customer needs, and experience." In this case, it has resulted in a transmission similar to, but yet very different from, its AS68 predecessor.

Compared to the AS68RC:

- The input shaft gear and output shafts are larger diameter to handle the greater torque capacity of the high-output Cummins engine.



Input shaft thickness for the AS69RC has been increased by almost 5 mm in the longest section. The spline also has been redesigned to handle the greater torque of the high-output Cummins engine. It has more teeth and a greater diameter than the one found on the AS68RC it replaces. The same is true of the output shaft which also has more splines and a greater diameter along its varying cross sections.

- The number of planetary gears in the P1 and P2 planetary gear sets were increased, with P1 going from six to eight, and P2 from four to five.

- To lower service costs, the primary and secondary regulator valves were moved from the oil pump to the valve body, eliminating the need to replace the oil pump if a valve body problem should occur.

**AS68RC (Old)**



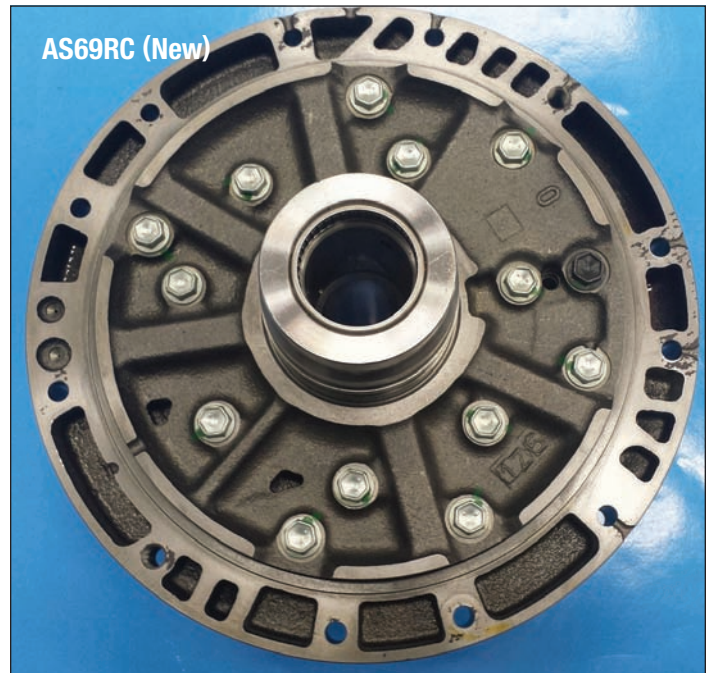
**AS68RC (Old)**



**AS69RC (New)**



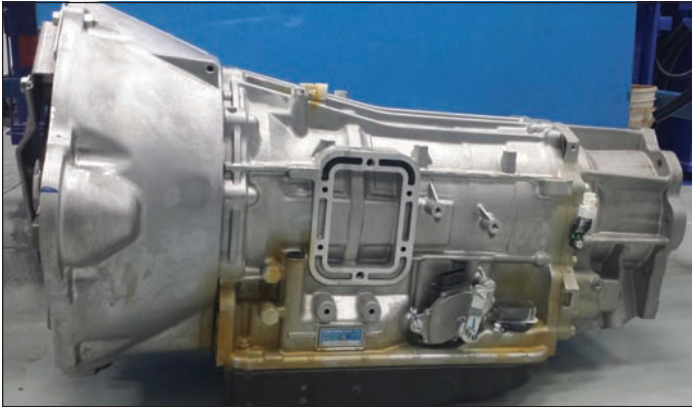
**AS69RC (New)**



Aisin increased the number of planetary gears in the P1 and P2 planetary gear sets. The AS68RC had six planetary gears in the P1 gear set, while the AS69RC has eight. Meanwhile, the P2 gear set (shown) now has five gears versus four for its predecessor.

The primary and secondary regulator valves found on the oil pump assembly of the AS68RC have been moved to the valve body on the AS69RC. It is no longer necessary to replace the oil pump if there is a failure in the valve body, lowering service costs.

- Power take-off capability was enhanced by adding an optional left-hand PTO opening. The standard configuration remains with the PTO opening on the right-hand side of the vehicle. This allows PTO installation on a 4WD vehicle. To help the Ram's competitive position, output capability of the PTO gear increased from 135 ft-lbs to 250 ft-lbs.



Aisin's new transmission has a cut-out cavity for a PTO on the left-hand side of the case. Previously, a power take off only could be attached to the right where it cleared the 4WD transfer case.

- To prevent their overloading, the transmission controller also manages transmission output torque to the axles.
- Potential failure modes were eliminated by using a single pressure switch on the valve body.
- Independent clutch-to-clutch control was improved by reengineering the control system (valve body, electronics, etc.).
- Power transfer losses were reduced by revising the material and groove pattern used on the friction discs, and fitting bigger clutch plates.
- In order to hold the vehicle under GCWR loads, a new park system was designed and developed.
- Redesigning the geartrain and increasing the torque loading also required a new main case, torque converter housing, and adaptor. The new torque converter improves launch performance under high torque and towing loads.
- The one-way clutch was eliminated to cut cost and complexity, and keep transmission length the same as the AS68 it replaces.

To continue with the interview, Senior Engineer Nehal Rahim continues with the dialog: "Obviously," says Rahim, "we do many miles of validation in vehicles, many hours on both electric- and engine-driven dynos, as well as component-level testing. And many of those are tested beyond anything you would see on a vehicle." The torque converter ballooning test is but one example. During a shift, torque spikes travel through the driveline. This causes the flex plate to shift and the torque converter to balloon, which means it must be able to slide on the input and stator shaft splines. That's a major reason it's attached to the engine flex plate and not the transmission. "The ballooning test pressurizes the torque converter to the point where it increases in width, and is unlike anything you'd see in service," says Rahim.



The one-way clutch of the AS68RC was eliminated to cut costs, complexity, and make room for the new automatic's larger torque converter in the same overall length. The new converter carries about half the transmission's ATF capacity and it must be able to slide on the input and stator splines during shifts.

To control the heat output of the high-output Cummins, the cooling system also was revised. In addition to dual radiators and a high-efficiency fan, dual transmission coolers and an in-tank, fluid-to-fluid cooler increase heat rejection capacity by 25%. However, this system also helps cool the engine by dumping some of its heat into the automatic transmission fluid's cooling system under most operating modes. To prevent overheating from occurring, Aisin lays out the transmission's cooling requirements for the OEM. However, should the transmission begin to overheat and its temperature warning light illuminate, a separate set of shift maps are used to bring the temperature down to normal levels. These maps change the points where the torque converter is locked/unlocked in each gear to reduce heat generation within the torque converter, which carries about half the transmission's fluid capacity. When the PTO is not in use, the warning light comes on when the temperature of the fluid leaving the torque converter crosses 293° F, and turns off when it returns to 248° F. During PTO operation, these limits are reduced to 248° F and 212° F.

"It's not possible to anticipate every possible situation the transmission will be subject to during its life," says Brown, "because the pickup market is diverse, and the Chassis Cab market is even more varied than that. Each case is different." Aisin's global footprint, however, allows it to draw from a deep well of experience. This allows Aisin to evaluate schedules, duty cycles and OEM requirements, and balance them against its own test cycles in order to create a robust design, even when the demands include taming 850 ft-lbs of American-made torque.

**Christopher Sawyer**  
Ram/Aisin Technical Writer

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## TRANSMISSION TEMPERATURE

When towing a 12,000 pound fifth-wheel trailer up a three mile long, seven percent grade, the transmission temperature gauge on the dash of my '14 Turbo Diesel 3500 with a 68RFE transmission climbed to 204 degrees. The ambient air temperature was 80 degrees. Is this normal?

**jackknife**

It appears normal to me. I usually see around 180 degrees driving my '12 Turbo Diesel 3500 with a 68RFE and a 3.73:1 axle ratio empty with the ambient temperature in the 40s and around 200 degrees towing 15,000 pounds with ambient temperature in the 60s.

**Terry Jay**

I advise keeping your transmission sump temperature at 230°F or below and cooler is usually better. Once it goes over 230°, begin looking for a place to stop and cool down. Brief spikes over 230 degrees are not a problem and you can hit 240, 250, 260, even 270 degrees for brief periods without instantly killing your transmission, but you shouldn't run for extended periods at these levels.

**TransEngineer, Grass Lake, MI**

I was reading the transmission temperature off of the factory gauge in dash. I do not know where the sensor is located. Thanks for the information.

**jackknife**

The transmission temperature gauge in the dash is read from a thermistor inside the solenoid module and that is sump temperature.

**TransEngineer, Grass Lake, MI**

The '14 Ram 1500 Hemi has a transmission heater that keeps the transmission at least 180°-185°, and many times it is right at 200° when towing without working it at all. The heater was added to get the fluid thin quickly for added fuel economy. I would not give your 204° transmission temperature a second thought. If you want to keep it cooler than warmer, use Tow-Haul and try to keep the torque converter locked at all times by selecting the correct gear.

**sag2, San Francisco Bay Area**

Why does the transmission temperature rise so dramatically when towing up a mountain? With the torque converter locked, I would think the temperature should stay constant.

**Too Tall**

I presume you are asking about towing at highway speeds with the torque converter clutch (TCC) locked and no heat is being generated within the converter. Basically, any inefficiency in the transmission is converted into heat. Let's suppose your transmission is 96 per cent efficient under these conditions. In 5th gear, the 68RFE is using two of the planetary gearsets to transmit torque, and it generally loses about one per cent per gearset. Also let's suppose the pumping losses to maintain line pressure and cooler flow are two per cent and it is in the right ballpark, which means four per cent of the total power coming from the engine is being converted into heat inside the transmission. This is the source of transmission heat even if the TCC is locked.

When climbing a grade, the power requirements go up significantly. For example, I recently looked at a computer simulation run that I did for a Ram 2500 with trailer. The exact figures will vary depending on weight, tire size, axle ratio, frontal area, etc., but for the particular configuration I was running, I found the propeller shaft torque required on level ground, at 50mph, was 211.7 ft-lbs. On a seven per cent grade at the same 50mph, the propeller shaft torque required was 890.5 ft-lbs. It takes over four times as much power to climb the grade as on level ground; therefore, there is over four times the amount of heat generated in the transmission when climbing a seven per cent grade versus on level ground and why the transmission sump temperature increases when towing grades.

**TransEngineer, Grass Lake, MI**

Is there anything to be gained from shifting these new automatic transmissions into Neutral when at an extended stop light versus remaining in Drive as far as keeping the transmission temperature cooler? I haven't owned an automatic transmission in years. It's a habit I have from the old days.

**Ram4Sam, Redlands, CA**

Yes, indeed. Shifting the transmission to Neutral when stopped at a light will definitely help to keep the transmission cooler. With the transmission in Drive at a stop, it is generating heat in the torque converter due to the speed difference between the engine at idle speed and transmission input shaft at zero speed. If you shift to Neutral, the transmission input shaft spins up to almost match the engine speed and almost no heat generated.

**TransEngineer, Grass Lake, MI**

**Editor's note: It is fitting that the comments by "Trans Engineer" closes out our "6.7-Liter" column. Perhaps the placement and the bold text have captured your attention?**

**The TDR is VERY fortunate to have input from folks in manufacturing, marketing service support and engineering who participate with articles in the magazine and responses to customer questions at our web site.**

**This response by Trans Engineer is a perfect example. No doubt all of us have wondered about our automatic transmissions and "how hot is too hot?" Likewise we all know an automatic transmission will heat-up under a load, but I was at a loss to fully explain the source of the heat knowing that the transmission was in lock-up mode.**

**With TransEngineer's explanation, I've got it!**

**Now, back to the Bill Stockard and Robert Patton, "Editor's School of Common Sense": Typically members ask, "When is the transmission at risk of making high temperatures?" Answer: Big trailer towing, low speed, around town, stuck in traffic or low speed backing to-and-fro at the camp site. The torque converter is un-locked, fluid is slushing in the 'ole slush box (actually being sheared inside the converter) and there is zero-to-minimal flow through the transmission's cooler core. Do your best to minimize these situations.**

## HOW HOT IS HOT: TRANSMISSION FLUID TEMPERATURES

(From TDR Issue 82, page 13)

Way back in Issue 42 there was continued disenchantment with the automatic transmission (47RH) used in '94-'98 trucks. Looking back, my assessment of the problem was that (let's be honest, now) the owners were overpowering the transmission with more than the 180hp/420 torque that was given in the latter years of the '94-'98 engine model run. Another problem that hurt the transmission's reputation were failures caused by leaking fluid/low fluid/loss of fluid attributed to marginal plastic quick connect fittings used in the transmission lines of the day. The plastic would get too hot, over time it became brittle and, as noted, eventually leak fluid. If my memory is correct, these fittings were changed in the 1997 timeframe.

Regardless of the problem's origin, transmission temperature was (and continues to be) a valid concern. So, here is a reprint of a chart printed way, way back in Issue 18 that gives you some background cause-and-effect data.

Judging the accurate versus inaccurate is often difficult. One cannot help but note the disparity between column A (Off-Road, February '98, page 62) and column B (Sports Truck, January '96, page 15). One would also like to know where the temperature readings are taken. Neither article noted the location of the sensor.

Transmission Life Expectancy Chart

|      | A       | B       | Notes from article B                                    |
|------|---------|---------|---------------------------------------------------------|
| 175° | 240,000 | 100,000 | Optimal heat level for oils, seals, clutches and plates |
| 195° | 120,000 | 50,000  | Day-to-day operation                                    |
| 220° | 50,000  | 20,000  | Oil viscosity begins to break down                      |
| 240° | 25,000  | 10,000  | Varnish begins to form                                  |
| 260° | 15,000  | 5,000   | Seals harden                                            |
| 295° | 4,000   | 1,500   | Plates slip                                             |
| 315° | 2,000   | 800     | Seals and clutches burn out                             |

**Editor's comment:** It matters not which column is accurate. The point in presenting the data is to show the negative effect of temperature. An interesting conclusion from both columns: From 220° to 240° to 260° as the temperature increases by 20°, the life expectancy is cut approximately in half.

Also note that above 195° the life expectancy drops dramatically.

Ram/Chrysler comment: Our experience is we agree with Column A data and not Column B data. This should be transmission sump and not outlet temperature. The sump temperature can be measured with a dipstick mounted or a pan installed thermocouple.

## BACK TO THE BASICS CHANGE ALL THE FLUID

by Robert Patton

Okay audience, we've covered a lot of ground in this issue's discussions on automatic transmissions. How about some nuts-and-bolts service tips you can use?

Back in Issue 64, we did an article on how to change all of the fluid in your automatic transmission. The '94-'07 service tip for the 47RH/47RE comes to us from TDR member "Matt B." I was the author of the "'07.5 – Newer 68RFE" article. Join me as we reprint these great common sense articles.

"Matt B" submitted his tip to us and his service procedure can save you from the fluid mess that accompanies an automatic transmission fluid service job. Matt's tip also allows you to change the majority of the transmission fluid.

The "majority of the fluid." What do you mean? In a typical drop-the-pan service you are only changing about half of the fluid, there is fluid that remains in the torque converter that does not drain. Okay, how do you change the majority?

Matt's technique can be used on '94-'07 trucks with the 47RH or 48RE automatic transmission.

### Owners with the '94 - '07 47RH or 48RE

If your transmission pan doesn't have a drain plug (read: your very first transmission fluid change), to provide for an easy fluid change, or if you want to change all of the fluid (net change 10-12 quarts), try this method. Pinch-off and then disconnect the return-to-transmission cooler line from the radiator (location: driver's side of vehicle; bottom corner of radiator just beside the radiator coolant/fluid drain petcock). Of the two transmission lines, this is the outboard line and (thankfully) it is the easily accessible line. Take the 1/2" rubber hose and bend it upward to prevent fluid drainage. Next, connect a three-foot length of 1/2" rubber "purge" hose to the metal flare coming from the radiator. Feed your rubber hose into a five-gallon container.



A view of the transmission liner from the front of a Second Generation. Follow the "cold" line back to the transmission cooler and disconnect the line at the junction point. Attach your purge hose to the metal flare at the transmission cooler.

With the truck in Park, depress the emergency brake, chock the tires, and then start the engine. Shift the transmission into Neutral. ATF will begin flowing into the container. Once the flow begins to dwindle, immediately turn off the engine. This technique will yield 10-12 quarts of fluid. Re-attach the 1/2" rubber hose/cooler line to the metal flare from the radiator. Continue with your transmission maintenance by dropping the pan. (The fluid is gone, so you will avoid the fluid bath that can happen with a full transmission sump.) Complete the transmission service by changing the filter.

### Owners With the '07.5 and Newer 68RFE

For this transmission, the transmission cooler lines attach to the cooler assembly using crimped hoses. Regardless, you can use the same technique to remove the fluid, but you have to find a different disconnect location. Inspection of the transmission cooler lines for the 68RFE reveals that the entry and exit fittings to the transmission are on the passenger side.

Which is supply, which is return? That's why you pay your \$35 TDR subscription—the editor gets to take the 50/50 challenge in hopes of discovering which line is the return line. Before exploratory removal, I tried diagnostics with an infrared temperature gun hoping to see a big temperature difference in the two fluid lines. Perhaps I should have waited for a hot summer day, but deadlines prevail and there was little temperature difference.

The fitting and cooler line that was easiest to reach was on the bottom. As luck would have it, this is the return-to-transmission line. Using a 1" wrench I disconnected it from the transmission. I found a 3/4" heater hose, 3' in length, and hose-clamped it onto the threaded fitting. The hose was directed into a five-gallon bucket.



The bottom cooler line is the return-to-transmission line. Remove it with a 1" open end wrench. Clamp a 3/4" ID hose over the threaded barb and direct the fluid into a 5-gallon bucket.

I noticed that both the supply and return lines were held with a brace on the driver's side of the transmission. For extra wiggle-room when removing the transmission pan, I removed the brace (14mm bolt) with allows the lines to be pushed out of the way.

With the truck in Park, depress the emergency brake, chock the tires then start the engine. Unlike the previous 47RH/47RE transmission, you can leave the truck in Park and there is flow to the transmission cooler/return-to-transmission line that you have disconnected. ATF will begin flowing into the container. Once the flow begins to dwindle, immediately turn off the engine. This technique on the 68RFE yielded 10 quarts (at least that is how much I put back into the transmission to get it to the proper level). Re-attach the cooler line to the transmission and continue your transmission maintenance by dropping the pan. The pan is held on with 8mm bolts. Remove the bolts and you'll find that Mopar RTV sealant holds the pan onto the body of the transmission. Start in the back corner and lightly tap the pan. For what it is worth, there was still enough fluid in the pan to cause a small cascade of ATF over the edge of the pan. Better a small fluid bath than a large one? Remove the pan. Complete the transmission service by changing the two transmission filters.

### Check Your Work

Refill transmission with Chrysler ATF+4 fluid. I could not find the capacity for the 68RFE in my Owner's Manual. Using my "drain through the hose" and pan removal method I found that 10 quarts were needed to replenish the transmission.

After refill, the correct procedure for checking your transmission fluid is outlined in your Owner's Manual.

- The vehicle must be on level ground.
- The engine should be running at curb idle speed for a minimum of 60 seconds.
- Fully apply parking brake.
- Place the gear selector briefly in each gear position, ending with the lever in N (Neutral)\*\*\* for the 47RH/48RE; P (Park) or N (Neutral) with the 68RFE
- Remove the dipstick and determine if the fluid is hot or warm. Hot fluid is approximately 180° F (82° C) which is the normal operating temperature after the vehicle has been driven at least 15 minutes. The fluid cannot be comfortably held between the finger tips. Warm is when fluid is between 85° - 125° F (29° - 52° C).
- Wipe the dipstick clean and reinsert until seated. Remove dipstick and note reading.
  - a) If the fluid is hot, the reading should be in the crosshatched area marked "OK."
  - b) If the fluid is warm, the reading should be between the two holes. If the fluid level indicates low, add sufficient fluid to bring to the proper level.
- Fluid is added through the dipstick tube.

\*\*\*If yours is a '94-'07 47RH/48RHE I cannot over-emphasize that the transmission fluid should be checked with the gear selector in Neutral. With the vehicle in Park, there is no fluid flow! Hence, if you take a transmission fluid level reading with the vehicle in Park, the reading will always be higher than it actually is. Additionally, should your transmission fluid become too hot, shift the transmission to Neutral — not Park — to ensure that there is fluid flow and thus the opportunity for fluid cooling.

If yours is the '07.5 – Newer, 68RFE there is fluid flow in Park or Neutral.

**Robert Patton**  
**TDR Staff**

### CONCLUSION – RAM AUTOMATIC TRANSMISSIONS 1994-2014

So, folks there you have it, multiple pages on Ram automatic transmissions, '94-'14.

Yes, we covered a lot of ground, but as I mentioned about half-way into the article, we just hit the tip of the iceberg. The day-to-day problems and solutions have been covered in previous magazines and in the magazine you have in hand. Also, the problems and solutions have been covered in 15 years of website forum operation and on a daily basis at our website. My thanks to all of you that participate, learn and help out your fellow Turbo Diesel owner. My thanks to Ram Powertrain Engineering and Aisin for their help with the Q & A and the article on the new Aisin AS69.

**Robert Patton**  
**TDR Staff**

# The Cummins 6.7-liter Engine '07.5-'12

## ALL ABOUT THE 6.7 ENGINE

by Robert Patton

*The following compilation of articles was done in the summer of 2014. The introduction will set the stage for this tutorial on the '07.5-2012 6.7-liter engine.*

It is hard to believe that the Cummins 6.7-liter engine was introduced almost eight years ago. And, until recently, the majority of these trucks were still in the hands of the original owners.

The passage of time brings us a new group of first-time 6.7-liter engine owners. The “newbie” has heard all kinds of stories about the engine, many of which just aren’t true.

In an effort to enlighten, educate and entertain, I’m going to pull several articles from the TDR magazine to give you the factual story on this engine. (Hold your horses. I know you really want to get to the question “Can I ditch the exhaust aftertreatment system?” The legal answer is, no! More on this later in the article.)

Let’s start with the story behind the 6.7 engine, the quest by Cummins to meet the 2010 exhaust emissions guidelines early—like three years early. Our “Background 6.7” gives you the details (Issue 78, page 82).

Next up, Issue 69 (pages 48-53) gives you “Bringing It Together” a look at the parts and pieces that make up the 6.7-liter aftertreatment system.

Issue 72 (pages 32-37) gives you a “Four-Year Update.”

Issue 84 (pages 14-18) covers the topic “Cleaning Your DPF” and “The 800-pound Gorilla.”

So, there you have it: industrial intrigue, hardware and software updates, cost of operation, and, finally, the particulars of “Can I ditch the system.”

I’m hopeful you enjoy reading about and learn from our Perfect Collection of articles on the 6.7-liter engine.

## BACKGROUND 6.7 (From Issue 78)



Let’s look at how emissions legislation dictates the engine architecture of your truck. For example consider the 6.7-liter engine that was introduced 1/1/2007. From [RB&G](#) the “2007 Emissions Strategy”:

It was a single sentence embedded in a 1,000-page EPA document. Bob Jorgensen, the executive director of Product Environmental Management, paused when he saw it.

What surprised Jorgensen, though, was a new provision that let engines of certain sizes be certified by the EPA using results from a chassis dynamometer test. Such a test measures emissions from the entire vehicle and is conducted on rollers with a driver behind the wheel of the vehicle.

Previously, emissions from engines in this category could only be measured on an engine dynamometer set to operate outside the vehicle.

The flexibility available to the manufacturer who could use such a test was significant.

Once Jorgensen communicated the rule provisions to senior leaders and engineers, the remaining work was for the technology experts to handle.

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If the Dodge Ram could meet the 2010 standard three years early, it would be the cleanest pickup truck available in all 50 states—a marketing tool for Chrysler and Cummins and a benefit to the environment.

It was important to keep Cummins' strategy a secret from competitors. Besides meeting the 2010 emissions standards early, this would be the first chassis-certified engine from Cummins. It would also introduce NOx adsorber aftertreatment technology for the first time in a vehicle of the Ram's size. All of these were thought to be a competitive advantage.

Additionally, as part of the new 2007 rules, the EPA mandated the use of ultra-low sulfur diesel fuel. It was going to cost the American Petroleum Institute's members billions of dollars to modify their refineries, prompting the Department of Energy (DOE) to ask EPA, "Why the rush?"

Anticipating that no manufacturers would comply with the 2010 standards early, the DOE—at the urging of the Petroleum Institute and its members—suggested the EPA ease up on the stringent sulfur standard during its three-year phase-in period.

But Cummins' strategy required the availability of ultra-low sulfur diesel fuel by 2007. The NOx adsorber to be used downstream of the Ram engine needed it to operate effectively and run cleaner. So the company lobbied against relaxing the deadline, and the EPA decided to leave the fuel provision unchanged.

"The EPA was very happy to be vindicated when a manufacturer said it was meeting the standard early and needed the fuel," Jorgensen says. "So on par, even though some of the company's engines were emitting at NOx levels near the 2004 standard, we were helping the EPA justify the adoption of ultra-low sulfur fuel early."

This was a significant benefit to the environment. When used with other emission-reduction technologies, ultra-low sulfur fuel enabled new on-highway diesel engines to produce 90 percent less particulate matter, and reduced emissions from all trucks operating on the highways. The net reduction in NOx emissions was huge—and immediate.

## BRINGING IT TOGETHER (From Issue 69)

by Jim Anderson

There have been articles in several previous issues of this magazine and on the Turbo Diesel Register website about how emission controls affect engine performance, longevity, and fuel mileage. These articles have covered segments of emission controls, particularly diesel particulate filters (DPF) on 2007 and later trucks, and their effects on fuel mileage and engine operation; but putting it all together in a cohesive document should lead to greater understanding since each previous article dealt with one system only.

Over the past twelve years, particularly the last three (2007-2010), emission controls and electronic control of engine functions have become increasingly common and increasingly complex. Your writer has found that the average truck owner doesn't fully understand these controls and how the controls and other engine systems must function properly together for the engine and the truck to run in a satisfactory manner. Without this knowledge and understanding of the parts and of the whole, the average driver is clueless in the event of trouble in one of these systems. Fortunately, the engine computer that controls it all can also report trouble codes to lead to a diagnosis and a proper repair. See Issue 64, pages 46-48, for an example of how complete the diagnostic trouble code (DTC) list has become for 2010 trucks. Each trouble code on that list is tied to the reporting of a sensor somewhere in the system. The computer has powerful diagnostics built in to simplify the diagnostics involved in fixing problems.

As an aside, the owner of a 2007.5 or later diesel pickup truck should think very carefully before deciding to turn up the power or tamper with emission control devices. In addition to possibly voiding a valuable engine warranty, owner experience is proving that modifications to fueling often results in other unintended consequences whose cost to repair can run into the thousands of dollars. See Issue 67, page 30 for more details on fueling modification boxes, Issue 67, page 33 for the editor's comments; and page 42 for emissions non-compliance penalties.

It is now time to put these discussions of the various parts and systems together and bring to you a better understanding of the complications and balances involved, how it all works, and how it affects the newest trucks and engines. This primer is intended to put it all in simple language and, hopefully, will assist you in making decisions about upgrading your old ride to a new one, or in diagnosing and repairing problems on your out-of-warranty present truck. The goal is to make emission control more understandable amid the hodgepodge of regulations engine makers must meet in order to sell their products in markets around the world. Exhaust emissions and fuels really are a worldwide concern, and not so suddenly, except in the U.S., everybody wants their products to be "green."

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I'll begin by saying that Cummins Incorporated still has the best pickup truck engine design in the marketplace, and has been able to meet all requirements of both the government and truck builders without undue owner burdens. In fact, the 6.7 liter Cummins engine in the newest Ram pickup trucks meets the 2010-2011 emission standards without the use of urea injection. They are the only company to do so, while Ford and GM have both been forced to use urea injection exhaust aftertreatment on all of their engines slated for use in pickup trucks. The cost per gallon of urea is said to be in excess of \$12, and 7 gallons of the stuff will last about 3500 miles of normal driving. That would add \$84 to the operating costs for 3500 miles of driving, a large hit to your operating bill. Almost all big rig truck engines built in 2010 and beyond will also use urea injection. As you can see, this additional and sizeable added expense raises operation cost per mile by many cents for the bowtie and blue oval brands. Diesel Urea Fluid contains 32.5% ammonia and the remainder is distilled water. This solution helps a NOx catalyst to reduce harmful exhaust gases to inert ones that can safely pass out a tailpipe to the atmosphere. The catalyst turns oxides of nitrogen into nitrogen and water.

If you think that current engine emission standards aren't tough to meet in terms of research and development, a good example to examine is Caterpillar's engine division. After many years of research, they decided the latest emission standards were too tough and the expense too great for compliance and they got out of the on-road engine business in 2007 after gaining a 30+% share of the lucrative trucking and motorhome chassis businesses. They now concentrate their research energies on the off-road engine business such as bulldozers, large generator sets, and drag pans, where emission control requirements are less stringent (for the time being), and where profits are apparently greater. They simply could not make their emissions strategy work using existing technology and without violating patents of other engine makers. They walked away from many millions of dollars of income. Cummins, on the other hand, did the research, developed some good ideas, and handily made the 2010 emissions cut in 2007 with their 6.7-liter diesel engine without the use of urea injection for their pickup truck engines. We, as customers, have surely benefited.

Much of exhaust emission control on current engines lies in combustion technology and the use of ultra low sulfur diesel fuel. The more complete the combustion of fuel particles in the cylinder combustion chamber, the less exhaust pollutants must be treated to meet emission standards. The strategy uses several methods to meet the need. The government decree for 2010-2016 says three standards must be met for tailpipe emissions.

The first is NOx, oxides of nitrogen, which causes smog. The Ram pickup is vehicle certified on chassis-dyno, and the NOx regulation is 0.2 g/mile. The Cab/Chassis is engine-dyno certified, and that regulation is 0.2 g/bhp-hr.

The second standard is HC, hydrocarbons, unburned fuel molecules, another contributor to smog, and a known carcinogen. The third is CO, carbon monoxide, which in higher concentrations can cause death because the blood in mammals (that includes us humans) has a greater affinity for CO than for oxygen (O2). Unfortunately, concentration of CO in human blood is cumulative, so breathing small amounts over long periods can be fatal. The blood takes it in quickly, but exchanges it for oxygen very slowly. For our '07.5 and newer pickup trucks these standards are met using a diesel oxidation catalyst (DOC), a NOx adsorber catalyst (NAC), and a diesel particulate filter (DPF) to catch carbon particles.

The emission control strategy for all three pollutants begins in the cylinder or combustion chamber of a diesel engine, where the goal is to keep combustion cool enough to limit NOx, yet hot enough to completely burn as much HC as possible. CO and CO2 (carbon dioxide) are a natural byproduct of combustion of hydrocarbon fuels and can easily be controlled by passing exhaust gases over a catalyst in a converter which strips away the oxygen molecule in the case of CO and the two molecules in the case of CO2 and passes the remaining carbon on to the diesel particulate trap. The remaining carbon atoms are dealt with separately, along with the carbon atom in HC and the nitrogen atom and the remaining oxygen atom in NOx, by burning them in a diesel particulate filter. The Nitrogen atoms are passed out the tailpipe as an inert gas. More about the DPF later.

As emissions controls became tighter, engine makers developed strategies to more carefully time the combustion event and to more carefully control the precise amount of fuel injected for each combustion event. They also developed combustion chamber designs to induce a correct amount of swirl to the incoming air to more completely atomize the fuel charge before combustion was completed. Thus we saw careful design of the combustion chamber in the cylinder head and the advent of a "shaped dish" in the piston top. The dish shape looks similar to that of an old metal milk pitcher. Research showed that too much air swirl actually inhibited combustion, while not enough swirl left unburned fuel particles at the edges of the combustion chamber, thus leading to higher emissions out the tailpipe. In the pictures, note that the top of the piston shows the spray pattern in gray, and favors keeping the fuel spray away from the edges of the piston top.



**Piston top spray pattern area is visible as gray; incomplete combustion areas are black. This piston is from a vintage '94-'98 12-valve engine. Notice that the piston bowl is offset. The reason for this is that the injectors on the 12-valve engines came into the cylinder head at an angle. On the 24-valve engines ('98.5-'02) and HPCR engines ('03-current) the piston bowl is centered to match-up with the injector that comes into the cylinder head from directly above.**

The next photo shows the shape of the bowl in the top of the piston. Using a blunt center area to disperse fuel and a carefully shaped bowl periphery, a swirl is induced in the incoming air to allow maximum combining of fuel and oxygen.



**A close-up of the same 12-valve piston showing the piston bowl shape. Note the blunt center top, curved sides.**

Fuel injector design was also improved to achieve better fuel atomization and more even dispersion of fuel droplets throughout the combustion chamber where they can better combine with their oxygen partners. This was done by spraying fuel at higher pressures through more holes at the nozzle to get more even dispersion of finer droplets.

Here's a little bit of history: Almost all diesel engines up to 1998 used a mechanical injection pump that sent a high pressure (3,000-14,000 psi) pulse of fuel from the injection pump, through a steel line, and into the fuel injector. The pressure rise at the injector opened the injector nozzle and fuel was sprayed into the cylinder as it neared top dead center where the air was squeezed tightly enough to raise its temperature high enough to light off the injected fuel. When air is compressed, it heats up, as discovered by Dr. Rudolf Diesel (I'll bet you've heard of him before) in the 1800s, and is still the principle of operation of all of today's diesel engines. Because the compressed air becomes so hot, no outside source of energy, such as a spark plug is required to initiate combustion. Just spray the fuel into the hot air and it lights off on its own. After 1993, diesel engines were required to meet an emissions standard, so there were modifications to limit injector pump fueling unless ample air was present, and a diesel catalytic converter was installed in the tailpipe (vintage '94.5-'98). Trucks still smoked, sometimes a lot. The smoke is a result of more fuel being injected into a cylinder than there is air to completely burn it, or from large fuel droplets sprayed into the combustion chamber that don't readily atomize and combine with available oxygen. Smoke is unburned/not completely burned fuel hydrocarbons.

In 1998.5, we saw the advent of electronic control of a mechanical fuel injection pump by means of a computer which controlled the timing and amount of fuel injected into the cylinder. The computer offered more precise control of the fuel charge timing to meet the then-new emission standard. As time went by, new requirements were made the law of the land, requiring ever more precise metering of fuel at the proper time. Maximum efficiency in a diesel engine is gained through combustion at highest cylinder temperatures and combustion pressures, but these parameters caused more exhaust pollution. What to do?

With mechanical injection pumps there was a delay between the time the pump sent the fuel squirt through the pipe to the injector and the time the injector took to react by putting a shot of fuel into the cylinder. To cut this delay and make the injection event more precise, the computer was called upon to time the opening and duration of the injection event by operating a solenoid on top of the injector. In all Cummins engines since 2003 (the high pressure, common rail fuel system design), fuel pressure is supplied by a high pressure pump (up to 26,000 psi) to a common rail manifold connected to each injector. Since fuel under high pressure is available at each injector at all times, the time between injector solenoid opening and the resulting shot of fuel is lessened.

To further complicate matters, current emission control strategy (2003 to present) requires that several shots of fuel be supplied for each combustion event, and that actual combustion take place over more degrees of crankshaft rotation rather than supplying one large shot at or near the piston's top dead center as was the plan prior to 2002 emission controls. Geez. A set of injectors that were formerly required to operate up to 250 times per minute, now must operate three to five times as often, and must meter smaller but increasingly precise amounts of fuel each and every time. The amount of fuel injected depends on fuel rail pressure and duration of injector opening. The computer counts its ones and zeros very fast to compute the fuel timing and duration, making up to 9,000 decisions per minute. Current emission strategy requires that for each combustion event, a small amount of fuel is injected slightly before the piston reaches top dead center. As this small fuel charge heats up and begins to light off, the piston has passed top dead center. Another larger injection event occurs when the piston is just past top dead center, lighting more quickly than the first shot because heat has increased in the combustion chamber, and a third squirt occurs even later to squeeze the last bit of power out of the event. With the 6.7-liter engine, fuel can be injected after the combustion event. This raw fuel is used for the regeneration/cleaning events that occur in the truck's emissions control devices. Thus with current emission strategy, less peak pressure is put on the piston to drive it downward, but it is applied over a longer period of time or over more degrees of crankshaft rotation. The piston is now doing "work" until it is almost 90 degrees past the top of its travel as hot combustion gases continue to expand. The goal is to keep the combustion chamber cooler by injecting less fuel at each injection event, yet get the maximum amount of "work" from the piston as it is forced down in the cylinder.

Meanwhile, other mechanical and electrical bits and pieces are doing their thing, too. One way to get more power from a given engine size is to force more air into the cylinder to allow more fuel to be burned. This is accomplished by use of a turbocharger. Think of it as a pair of fans on a common shaft where spent exhaust gases exiting the cylinder turn a set of fan blades attached to another fan that stuffs more incoming air into the engine. The drawback (there's always at least one) is that when you compress air it gets hot, as Dr. Diesel found, but in this case, hot air coming into an engine is an enemy. So intake air going into the engine from the turbocharger is first run through an intercooler, a big radiator, where the compressed air is cooled from, say, 350° to under 150° before it enters the engine's air intake tract. The cooled air is more dense, contains more oxygen molecules, and therefore can be combined with more fuel droplets to make more power. A small turbocharger that spools up quickly ensures excess air is always present to burn the injected fuel, although at the expense of high rpm power. At the same time, the cooled air does its part in helping control combustion chamber temperatures for lower NO<sub>x</sub> emissions.

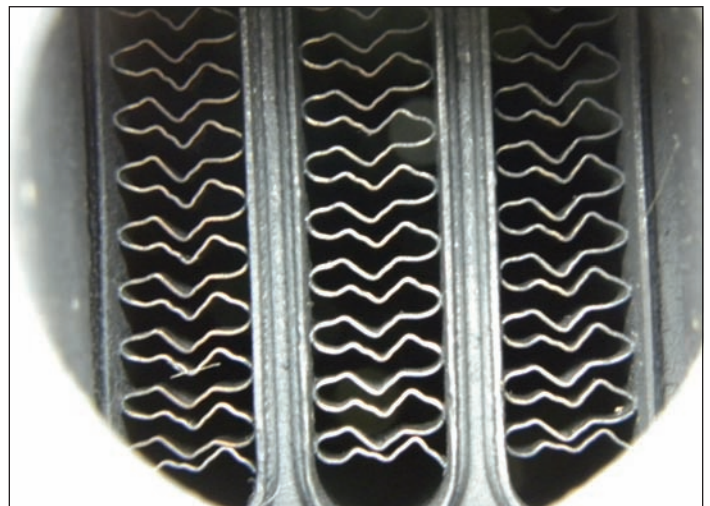
### Focus on the 6.7's Exhaust Aftertreatment

On the latest engines ('07.5 and newer), under certain engine operating conditions, some of the exhaust gases are recirculated into the incoming air intake to further reduce exhaust emissions. This cooled exhaust gas recirculation (EGR) puts inert gases into the cylinder that would otherwise be occupied by oxygen rich air while a smaller amount of fuel is added to make power. The recirculated exhaust gas is therefore more completely burned, lessening exhaust emissions, and the cooled inert gas further cools the combustion chamber to reduce NO<sub>x</sub> emissions. Exhaust Gas Recirculation is controlled by a valve that is actuated by the engine control computer.

These exhaust gasses are run through a small radiator mounted on the engine that is also supplied with a constant flow of coolant from the truck's radiator. It is a stainless steel tube with a small radiator mounted inside, where exhaust gasses up to 1,300° are cooled to around 200° before being routed into the engine's air intake manifold. Of course there is additional coolant plumbing and exhaust plumbing required for the EGR system. Unfortunately, a failure of the small EGR radiator will introduce coolant into the engine cylinders which can damage pistons and fuel injectors. This failure condition poses a particular problem with Ford 6.4-liter engine which uses three of these coolers; the GM Duramax engine uses two; and the Cummins 6.7-liter engine uses only one.



**EGR cooler. Coolant enters and exits through round ports while exhaust gases enter and exit at ends.**



**End view of cooler shows radiator inside.**

The other components that make up the 6.7-liter's exhaust aftertreatment system were mentioned before, the DOC, NAC and DPF. The DOC and NAC treat both  $\text{NO}_x$  and HC emissions by chemically changing them to more inert and less harmful gases. A catalyst causes chemical changes in a gas or liquid without changing itself.

How do these components operate? A quick look back at Issue 67 tells the story:

"The system begins with a close-coupled catalyst—essentially a conventional diesel oxidation catalyst (DOC) incorporating a metallic substrate—mounted to a short downpipe just off the back of the turbocharger. A short distance behind and below the close-coupled catalyst is the  $\text{NO}_x$  adsorber unit (NAC), which is followed by a diesel particulate filter (DPF). Both the NAC and DPF use ceramic substrates.



These components were taken from a Cummins test vehicle.

1. diesel oxidation catalyst (DOC)
2.  $\text{NO}_x$  adsorber catalyst (NAC)
3. diesel particulate filter (DPF)

"A NAC resembles a conventional catalyst, incorporating a catalytic substrate through which diesel exhaust is directed. Then the  $\text{NO}_x$  molecules are collected and held—'adsorbed'—onto the surface of the substrate, removing them from the exhaust stream. When the surface area of the substrate is full, the adsorber is regenerated with heat used to chemically change the  $\text{NO}_x$  into more benign gases, mostly nitrogen and oxygen.

"The NAC is regenerated every few minutes at approximately 600° to 800°F and the process takes about three to five seconds. The NAC will also, over time, collect sulfur from the fuel, which will gradually reduce its effectiveness. So depending on how much fuel is burned—typically every two tankfuls, a separate regeneration cycle is initiated to remove the sulfur. The use of high sulfur fuel is not allowed because it results in a high degradation rate of this catalyst."

The final part of the system is the DPF. The diesel particulate filter catches remaining carbon particles and burns them up. Where does the DPF get its heat for the burning process? Sensors in the DPF tell the computer when to go into its regeneration mode to burn away accumulated carbon. A few shots of raw diesel fuel are injected into a cylinder's combustion chamber while the exhaust valve is open. The late post-injected fuel is actually oxidized across the DOC and NAC, creating the higher temperatures (1050° – 1150°) required to oxidize the soot (carbon) off of the DPF. The fuel doesn't actually burn in the DPF to accomplish the DeSoot regeneration. About the only thing left to come out of the tailpipe is some moisture, some nitrogen, and carbon dioxide. The tailpipe exit on the newest trucks is cleaner than that of a gasoline engine. Nitrogen, coming out the tailpipe is the largest component of the air we breathe, so it poses no problem there as far as the EPA is concerned.

But wait... there's more! The engine control computer (ECU) mentioned earlier controls the whole thing and must have inputs from sensors in order to make proper decisions if it is to control the whole process from beginning to end. Stored in the computer are a bunch of "maps" that tell it how to operate and what commands to issue under any given engine operating condition. To know which map to use and what commands to issue, the computer requires inputs from a number of sensors, ranging from ambient air temperature, to intake manifold air temperature and pressure, to a throttle position sensor, to an engine speed sensor, and so on. Because it is all related, there must also be sensors to measure back pressure and oxygen content in the diesel particulate filter. The computer then also makes decisions about when to initiate burning off of the carbon particles in the particulate filter.

In the latest trucks, because the computer controls battery charging, a sensor even measures battery temperature while another measures voltage. There's a lot of electricity being used here and the computer must have a dependable and proper power supply to operate correctly. Yet another set of sensors inputs signals to the computer which then issues commands controlling automatic transmission operation. Of course, engine and transmission operation are interrelated, so the computer changes to a different control "map" at every transmission shift and at many changes in throttle position because engine operation changes as engine speed and load change.

There's even computer input from sensors in the brake system. For example: If vehicle speed is zero and your foot is on the brake pedal and the transmission is in gear, engine speed is limited if you simultaneously press on the "go" pedal. The computer decides this is a no-no and limits engine speed to about 1500 rpm to avoid transmission damage. It seems that the engine's control unit has thought of just about everything except how you like your coffee.

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### The 6.7-liter Cab and Chassis Engine

Urea injection will be used on Dodge Cab/Chassis models in 2011 because its EPA "duty cycle" is different than that of a pickup truck. Although urea is a commonly available chemical, and is a component of urine and fertilizer, Diesel Emission Fluid (DEF) is a highly refined, high quality urea chemical made from synthesizing natural gas. A spray nozzle with an opening smaller than a pencil lead dispenses the DEF fluid into the exhaust stream just as it passes over a catalyst to treat the NO<sub>x</sub> component.

The urea injection, known as selective catalytic reduction (SCR), takes the place of the NAC unit that is used on the 6.7-liter engine in the 2500/3500 pickup trucks.

Almost all large truck engines used in 2010 and beyond will use urea injection in their emission control strategies. The cost of the system adds about \$1,000 to the price of a diesel powered truck, and there is a space requirement for the urea tank, pump, and plumbing that must be found somewhere on the chassis. The system also uses sensors to report operation and tank quantity remaining, and DEF systems may not allow the vehicle to restart if the tank becomes empty. There is even a sensor that reports if the tank is filled with another liquid such as water, or fertilizer mixed in water, so you can't cheat it. A signal from this sensor will also prevent restart.

With the 2011 Cab/Chassis truck there is ample warning time before the engine will not restart. First a low DEF level warning on the EVIC with occasional chimes, and then a 500 mile countdown, with increasing frequency of chimes. If the driver ignores the 500 mile countdown warning on his EVIC display, after hitting zero miles, the engine will not restart due to starter lock-out. It won't restart until enough DEF is added to bring the level above the start of inducement (~ 2 gallon).

So what are the next generations of engines going to feature in the never ending quest for greater efficiency along with ever tougher emissions standards? In the near future, piezo electric actuators will replace fuel injector solenoids. In fact, they are already being used in some truck and automobile engines. Piezo crystals quickly swell when electricity is applied to them, so they can be used to operate fuel injectors. They're faster acting than solenoids so there would be another improvement in the accurate metering of fuel, so important in the emissions control game.

Piezo electric actuators could also be used to operate engine intake and exhaust valves to open and close at more precise times than those allowed by a camshaft, pushrods, and rocker arms, with the attendant "slop" in linkages. Not only would this eliminate the camshaft, pushrods, and rocker arms, all weighty pieces, but electronic control of valve timing would allow varying these events to further improve engine efficiency at various engine speeds and loads. The computer technology is already on board to accomplish these tasks, and variable valve timing is already proven in use in many gasoline engines for increased efficiency and power.

To meet upcoming increased fuel mileage mandates, research is in progress with the goal of cutting internal engine friction. This would yield more power while building less internal heat. At present, about 20 percent of fuel consumed by an engine goes to overcoming friction both inside the engine and throughout the rest of the drive train, including the tires.

The next area for further development will be the engine cooling system. Heat rejection from the combustion process wastes a large portion of the heat value of the fuel burned in the combustion chambers. Capturing this heat to do useful work other than warming your toes on cold mornings would offer further gains in fuel mileage.

With increasing electronics use comes more electrical power consumption. Look for future vehicles to use higher voltage electrical systems, either 24 or 48 volts. Doubling the voltage means one-half the amperage draw, so alternators, electrical motors, actuators, and batteries can all be made smaller, thus saving weight and space. Military vehicles have used 24 volt systems for many years, so the technology and hardware already exists.

There is little industry buzz about designing hybrid trucks. The power density of today's battery packs is simply too low to effectively move a load over long distances, and would be very marginal for even short distances with heavy loads. Diesel/hydraulic or diesel/electric power offers better returns as an alternative prime mover.

Today, only about ten percent of the fuel used by an engine does useful work in moving the vehicle. The other 90 percent is lost by factors mentioned above and by wind resistance. For example, in a truck moving at 60 miles per hour, about 50% of the engine's power is used just to overcome wind resistance. Cutting all of these losses means a net gain in fuel mileage and vehicle efficiency. That translates to good news at the fuel pump.

**Jim Anderson**  
TDR Writer

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## **FOUR YEAR UPDATE — 6.7-LITER ENGINE REPORT FOR 2007.5-2011 ENGINES (From Issue 72)**

by Robert Patton

In this issue's editorial you'll note the challenge that we presented to the TDR's writing staff—provide an all encompassing view of a topic. The writers were also asked to maintain their focus with articles that were brief and to the point. My assignment was to give 6.7-liter engine owners an update.

In order to present fresh and new information one has to assume that the reader is up to date on the 6.7-liter engine and its aftertreatment hardware. To that end, I researched and reread the materials in past TDR magazines to make sure that there were no updates needed. So, for those that need to come up to speed on the engine, the reference articles are:

Issue 62: pages 74-79, "What's Up with the New 6.7-Liter Engine?"

Issue 63: page 46, "The Next Emissions Hurdle"; pages 50, 51, "Ownership Report"; page 54, "6.7-Liter Update."

Issue 65: pages 42-43, "6.7-Liter: Ask the Engineer."

Issue 66: page 40, "The Regeneration Process."

Issue 67: pages 46-56, "The 2010 Ram HD Trucks, A TDR Writer Report"; pages 30-34, "Performance Enhancements for the 6.7-Liter Engine."

Issue 68: pages 42-48, "Fourth Generation Ask the Engineer – Truck and Engine."

Issue 69: pages 48-53, "Emissions – Bringing It Together"

Issue 71: pages 54-58, "The Editor Buys a Fourth Generation Truck."

Wow, Mister Editor, that is a lot of research. Can you shorten it down to, maybe, three or four major questions?

Okay, sure. What you really want to know is:

- With four years under-the-belt, how is the engine's reliability?
- What is the miles-per-gallon story?
- What is the regeneration story?
- What do I recommend?

### **How is the Engine's Reliability?**

I have noticed that the question of durability typically does not come up with Turbo Diesel owners or potential owners. With the exception of the Block 53 problems seen on '98.5—'01 vintage engines (Issue 62, page 22, and Issue 60, page 114, have the details), durability of the Cummins 5.9-liter or the new 6.7-liter has never been questioned. Can the Ford and GM customers say the same?

Reliability. Each vintage of Cummins engine has its share of quirks. From dowel pins, to fuel transfer pumps, to injector life of 150,000 miles, TDR members have met the challenge and serve as the resource that alerts other members to a problem—you show others how to repair them. That's the fact. The specific spotlight in this article is directed onto the 6.7-liter engine and the question of its reliability. And from what I have observed as editor, the real issue of this engine's reliability is not so much engine components as it is on the emissions control devices (ECDs) and updates in the engine control module (ECM) to manage them.

Before I get into the nuts and bolts (or the bits and bytes?) of my exposition, I want to re-emphasize the overriding advantages our new 2011 owner has over competitive Ford or GM trucks. The Dodge and Cummins folks have four years in the saddle with the 6.7-liter engine, which, as you know, met the 2010 emissions standards three long years early. We can certainly conjecture that the competitors will have their share of teething problems.

But back to the main story: the reliability of the 6.7-liter engine. First off, we need to note that we are actually looking at two unique engines with different ECDs based on emissions testing applied to each one's respective product category. Specifically I refer to the difference between (1) consumer 2500 and 3500 models to which are applied an EPA emissions test based on a drive cycle; and (2) commercial cab and chassis 3500, 4500, 5500 models subject to an EPA emissions test where the engine is on a stationary dynamometer. Recognizing this distinction, I will treat each category separately.

First, reliability of the '07.5–11, 6.7-liter consumer 2500 and 3500 engine: in assessing reliability, we note that this engine has an additional ECD piece of hardware that the cab and chassis truck do not have, namely a NAC or nitrogen oxide (NOx) absorber catalyst. (Issue 62, page 78, has a technical discussion that covers the NAC.)

This engine has had its share of problems traced back to soot accumulation, problems addressed by Chrysler in several service bulletins and two recalls. It has been a fraught issue and received considerable attention before it could be resolved. Because questions may remain for some users today, I will put the matter in context and summarize its history. I am guided by information gained in discussions with the men who work on the trucks for a living every day at Dodge dealerships. There is no more reliable source.

In my summary, I cite two relevant recalls addressing this issue: the first, known as G30, was dated October 2007: the latest, "Emissions Recall J35," was dated April 2010. I start with G30 to emphasize that there was period of nearly three years during which Cummins and Chrysler analyzed the problem to devise solutions. The most direct way to understand the initial problem and its eventual fix, is to review the text of the J35 recall as it was published in our Issue 70 magazine, re-printed herewith.

Date: April 2010

Models: '07.5-'09 (DHID1) Dodge Ram 2500/3500 Pickup Truck

This recall applies only to the above vehicles equipped with a 6.7-liter diesel engine (sale code ETJ). The Engine Control Module (ECM) software program on the above vehicles may cause illumination of the Malfunction Indicator Lamp (MIL) when no problem exists or under certain conditions allow heavy sooting of the turbocharger, exhaust gas recirculation valve and diesel particulate filter. Heavy sooting could damage emissions components and result in increased emissions.

Repair: The Engine Control Module must be reprogrammed (flashed). The bulletin describes the service procedure that the dealership technician is to follow. Using the dealership's scan tools, the time allowance for the reprogramming operation is less than one hour. As a part of the recall and ECM update the technician has to verify that the previous emissions recall, recall G30, October 2007, has been performed. The G30 recall contains software that must be installed to prevent damage to the ECM. There are no parts involved in the J35 recall notice.

As I read it, the most significant statement in the J35 recall is that "there are no parts involved in the J35 recall notice." Prior to the software updates it prescribes, there had been a series of technical service bulletins (TSBs) instructing the dealerships in how to clean turbochargers and how to wrap sensors to retain heat, and prescribing a series of "flashes" to reprogram the ECU. With the J35 recall, issued and acted upon a year ago, this vexing issue seems to have been solved. We can assume that now it is history.

Now, the '07.5-'09 cab and chassis engines: The emissions test for a commercial cab and chassis is done on an engine dyno rather than an EPA driving cycle. Therefore, these engines do not have the NAC hardware. Would you believe me if I told you that the problems with this engine have been minimal?

Finally, the new '11 cab and chassis engine with urea injection: While it is true that the '07.5, 6.7-liter consumer 2500 and 3500 trucks met the EPA's 2010 emissions standards three years early, the engine in the cab and chassis were not fitted with the necessary urea injection until the official due date of 1/1/2010. The report card on these engines has not been completed.

### What is the MPG Story?

As the editor, with firsthand knowledge about the 6.7-liter engine since 8/07, I'll tackle this question. I'm going to share with you the short answer, the competitive story, and then the long story.

The short answer: The Issue 67 magazine, pages 30-33, has a listing of performance items/tuners that are available for the 6.7-liter engine. It also gives my view on the hype created by internet town-criers with their claims of "increased fuel mileage of 5mpg." My response bears repeating:

"Yet, with the continuous barrage of criers, magazines and advertisements, one has to wonder, 'Is there validity to such hype?' Without thinking thoroughly about the question, I asked a group of Cummins' engineers. They were candid in their response. To summarize, one has to consider the duty cycle of the truck. If it is being used as intended—moderate to high load in highway travel—the answer is the obvious: the engine's output of unburned fuel (particulates) is very low, the exhaust gas temperature is high and there is little need to fire-up the self-cleaning oven known as the diesel particulate filter. Consequently the mileage penalty is negligible, if any at all.

"If the truck is being used as a grocery-getter or has long periods of idling there can be an effect on fuel mileage. How much? The estimate is less than 5%. Five-percent is nowhere close to the claims of 5mpg."

Also, the Issue 67 magazine, pages 42-44, had all the details regarding emissions compliance.

The competitive story: From Issue 71 you likely noted the reference to a test done by the folks at [www.pickuptrucks.com](http://www.pickuptrucks.com) titled the "Diesel Shootout."

I have been on the lookout for other apples-to-apples comparisons but I've not seen any better than the one done by pickuptrucks.com. The following are the numbers from my Issue 71 summary of their 16 pages of text:

| ¾-Ton | Unloaded | w/Trailer | Combined | DEF Consumption |
|-------|----------|-----------|----------|-----------------|
| GM    | 19.66    | 13.28     | 15.85    | 1750 (mL)       |
| Ford  | 18.55    | 13.91     | 15.90    | 360 (mL)        |
| Ram   | 17.20    | 12.38     | 14.39    |                 |

| 1-Ton | Unloaded | w/Trailer | Combined | DEF Consumption |
|-------|----------|-----------|----------|-----------------|
| GM    | 17.96    | 11.04     | 13.67    | 2760 (mL)       |
| Ford  | 17.32    | 12.69     | 14.64    | 2650 (mL)       |
| Ram   | 14.53    | 11.21     | 12.65    |                 |

If you want to fish for red herrings, you can plug in the cost for DEF and do some awkward mathematics to try and compute an overall cost-for-fuel and DEF. The math is not going to make up a difference (based on their "combined" results) of 1.5mpg (¾-ton trucks) or a 1 to 2mpg (one-ton trucks). Ouch.

The long story: I have a close friend that read the words from the internet town criers about "increased fuel mileage of 5mpg." His comment, "There is only one way to find out, right?"

So, armed with credit card, a metal sawzall, and tin snips to cut and fit some exhaust gas recirculation (EGR) block-off plates, I sent him to work on his '07.5 6.7-liter engine.

He had logged about 10,000 miles on the engine prior to the decision to "walk on the wild side." He was fully aware that the emissions control device (ECDs) deletes were illegal and that he would have no rights to warranty consideration. The temptation of an additional 5mpg was too good to pass up.

First up, order the turbo-back ECD delete pipes, dummy sensors, and the EGR block off plates. The \$700 kit was installed and off he went to tow for a modest 12-hour round trip. Thirty-minutes into the return trip the overhead console chimes and the message reads "Diesel Particulate Filter (DPF) full, See Dealer." I get the frantic phone call asking "What should I do?" My answer, "Keep driving and hope that the truck does not go into a limp-home mode. After all, you've only got 5 hours, 30 minutes remaining on your trip.

Aside from the console chime every 10-minutes, he made it back to the home base without the inconvenience of derate. The next day the first order of business was to call the “ECD delete dudes” and quiz them about their pipes and sensors. His question, “Why did the message ‘DPF full’ come up, it no longer has a DPF?” Their answer, “Not really sure, man. Guess you need to spend another \$900 with us and get the Edge Products module that allows you to reset the fault codes and clear the codes each and every time you start the truck.”

It looks like the temptation of an additional 5mpg was too good to be true...

So, my close friend was into this project for a cool \$1600 and, should a problem arise, he now had no hope for any type of future warranty consideration.

Over the next 2.5 years and 30,000 miles the engine ran without any problems. However, the fuel mileage was, at best, about .5 mpg better when towing (up from 10.0 to 10.5) and the around town mileage up by .75 mpg (13.5 to 14.25). The around town number is a close approximation as his truck is used only when towing. Yes, the lure of 5mpg was too good to be true.

But wait, there is more: three years and 35,000 miles into his ownership the truck starts spitting white smoke and raw fuel out the exhaust. Again I get the frantic phone call asking, “What should I do?” My answer, “I don’t know, this sounds expensive.”

He brought the truck over to our office. Sure enough, no matter how many times you reset the fault codes, the engine still would spit out raw fuel within a matter of .2 miles of driving. So, we removed the Edge box and all of its associated wiring from the vehicle. No difference. Next, we put the Edge back on. No difference. Then, we took the Edge off again. No difference. Then I reminded my friend that “You are your own warranty station.”

He did not see the humor in my comment.

As a part of the Issue 67 report that I did on “Performance Upgrades for the 6.7-liter Engine” I had purchased a MADS Electronics “Smarty S67.” I, too, was interested in the too-good-to-be-true mileage claims and had the best of intentions to do a Society of Automotive Engineers (SAE) type fuel mileage comparison. But, based on the data collected by the white smoke/raw fuel truck sitting in the TDR’s parking lot, I had determined that the money, time and effort to do an SAE mileage test would not prove anything. So, we decided to put the \$685 MADS “Smarty S67” to work on his truck.

The S67 is a downloader that reprograms the ECU. You plug into the trucks OBDII port and choose one of many different power levels. The choice we made was “stock with timing for fuel economy.”

With the download completed, we started the truck and drove .2 mile before the white smoke/raw fuel came bellowing out of the tailpipe. This time I made the frantic phone call. I called my good friend, Mark Chapple, owner of TST Products ([www.tstproducts.com](http://www.tstproducts.com)). I had purchased the S67 from TST and Mark was quick with his what-to-do response. “I want you to go to the MADS web site

and download your Smarty S67 with the ‘ME’ program. ME stands for Middle Eastern where the 6.7 engine operates without the fancy emission stuff. So the ME program will likely ignore some sensor or timer that is telling the engine’s injectors to operate after the combustion event, using fuel to ignite an aftertreatment device that is no longer on the truck.”

We downloaded the ME program. The white smoke problem went away.

Subsequent fuel mileage data using the Smarty S67 told the same story, about .5 mpg better when towing, up from 10.0 to 10.5.

And, now, the moral of the story: My friend has spent \$2285 in his pursuit of a .5mpg improvement in towing. He has no rights to warranty consideration and he has spent lots of time upset by his costly mistake(s).

Is there something to be learned here?

Now, for more on the MPG story continue your reading with “The Regeneration Story.”

### What is the Regeneration Story?

Did you notice the “Product Showcase” write-up in Issue 71 on pages 146 and 147, about the new gauge package from Edge Products called the Edge Insight Color Touch Screen (CTS)?

Chances are you breezed right over it. Had I not written the article, I would have been guilty of the same.

I am again writing about their product because it offers several benefits beyond the conventional analog gauges that we’ve all used in the past:

- For equal to the cost of a boost, EGT, transmission temp gauges and the associated pods you can purchase the Insight CTS (price, less than \$400)
- The Insight CTS gives you (by my count) 17 more items that can be monitored
- To install the Insight you simply plug into the truck’s OBDII port
- Added benefit—the ability to read and reset diagnostic trouble codes
- Added benefit—the ability to do performance testing

However, the Insight feature that is the focus of this article is the display of the regeneration status, “Regeneration On or Off.”

The Insight CTS isn’t the first monitor to display this information; the previous Edge monitor (the “Attitude” monitor used with the Edge “Juice” performance module) would do the same. And, likely, there were other brands of monitors that would display the regeneration status. But, can you recall a report anywhere in the TDR, or on the TDR’s web site or anywhere else in print or web where the author talked about the frequency of regeneration over a 1,000 mile test drive?

Me neither. So, since I am often accused of having my head in the sand, I asked those that surf the web and several TDR writers if they could recall such a write-up. I even asked the product representative at Edge if such an observation had been done. The consensus as to why: likely those that purchased a monitor also purchased the performance box. Likely they ran over a big bump in the road that caused all of the emission control devices (ECDs) to fall off of the truck. Can you think of any other reason that such a report has not been filed?

With the background discussion out about why such an observation had not been done, here is my report on when the regeneration cycle(s) start; when they stop; the corresponding observed fuel mileage; and the temperatures associated with regeneration. That's right folks; we're trying to define, "What is normal?"

The observations are based on three different driving cycles: the in-town loop; the 700 mile and 1,000 mile interstate trips; and the 600 mile towing trip.

Finally, realize that the following numbers are not scientific tests, but rather observations on previous trips. I have verified the truck's indicated MPG with the fuel required to fill the tank. However, this series of observations that you'll read about make the assumption that the indicated MPG can be trusted for a less-than-tankfull event.

#### The in-town loop:

I started this observation in mid-January and the weather was in the mid-20° to mid-40° range. The cold weather combined with a driving loop of less than 8 miles per day put the truck into a regeneration cycle that I will call the "dufus zone." The dufus zone looks like this:

| Reset | On | Off | Notes            |
|-------|----|-----|------------------|
| 0     | .9 | 3.7 | stop – warehouse |
| 0     | .8 | 3.7 | stop – home      |
| 0     | .6 | 3.7 | stop – warehouse |
| 0     | .9 | 3.7 | stop – home      |
| 0     | .7 | 3.7 | stop – warehouse |
| 0     | .5 | 3.7 | stop – home      |

And so it went for eight consecutive trips to and from the warehouse to home. The regeneration would turn on after pulling out of the subdivision, still on when parking the truck at the warehouse or home destination. EGT readings would be less than 700°, the NOx absorber reading would climb to 950°.

Finally, I had a chance to drive on the interstate and I logged the following data:

The regeneration came on as I pulled out of the parking lot. From there it was 2 miles to the freeway. I settled into the flow of traffic (approximately 70mph) and reset the "Fuel Economy MPG."

The regeneration stayed on for 20.8 miles; indicated MPG, 14.2. The temperature at the NOx rose to, and stayed at 1100°.

The regeneration stayed off for the next 114 miles as I completed a town-to-town interstate loop: indicated MPG, 17.3.

#### The interstate trips:

Next up, the 700+ mile interstate trip and the 1000+ mile interstate trip.

On the tail end of the "off for 114 miles" interstate trip, the truck putzed around town getting ready for the 700 mile trip. As I have come to expect, the regeneration came on almost as soon as I hit the road for the 700 mile trip from Atlanta, Georgia, to Hilton Head, South Carolina. I set the cruise control at 75mph.

The regeneration was on for 18 miles; indicated MPG, 14.7

The regeneration was off for 188 miles: indicated MPG, 17.6

The regeneration was on for 26 miles; indicated MPG, 13.9

The regeneration was off for the balance of the trip to our destination (64 miles) and it stayed off in around town traffic for another 49 miles, total off 113, MPG 15.8.

I'm starting to see a pattern, how about you? The balance of the trip:

|                    | MPG  | Notes                               |
|--------------------|------|-------------------------------------|
| On for 12 miles,   | 12.2 | : in town                           |
| Off for 87 miles,  | 16.7 | : country roads and in town         |
| On for 19 miles,   | 13.6 | : in town                           |
| Off for 52 miles,  | 15.9 | : in town to interstate             |
| On for 29 miles,   | 14.5 | : interstate travel                 |
| Off for 169 miles, | 17.1 | : interstate travel, return to home |

Observation for this trip:

Each time the regeneration comes on the temperature at the NOx catalyst goes to 1100°, EGT can be 250° cooler as the truck is going down the interstate at 75mph. The driving style did not change with the on or off status. Adding up the total miles: 713

"On" miles – 104; average\* indicated MPG – 13.78

"Off" miles – 609; average\* indicated MPG – 16.62

"On mileage penalty = 2.84

\*The average of the "average indicated" is not a weighted average, but rather the MPG numbers added together and divided by the number of "Ons" and "Offs." Not scientific, but rather, a casual observation.

For the 1000+ mile trip the truck went from Atlanta, Georgia to Orlando, Florida, a straight shot down Interstate 75. The driver was Geno's Garage employee Scott Sinkinson. Scott set the cruise control on 78mph. After putzing around town to get ready for the trip the regenerations came on just as he put the truck onto the interstate.

|                    | MPG  | Notes          |
|--------------------|------|----------------|
| On for 20 miles,   | 13.0 | All interstate |
| Off for 240 miles, | 15.4 | " "            |
| On for 23 miles,   | 13.1 | " "            |
| Off for 237 miles, | 15.3 | " "            |
| On for 21 miles,   | 12.9 | " "            |
| Off for 245 miles, | 16.2 | " "            |
| On for 19 miles,   | 12.3 | " "            |
| Off for 239 miles, | 16.5 | " "            |

### Observations for this trip:

Compared to the MPG of the previous 700 mile trip it is obvious that speed cost mileage. Perhaps a fuel price of \$4 will slow these drivers down. Scott had some side wind in both his south and north bound travels. Being on the interstate in a non-changing environment really brought out consistency in the on-and-off events. Adding up the total miles: 1,044

"On" miles – 83; average indicated MPG – 12.82

"Off" miles – 961; average indicated MPG – 15.85

"On" mileage penalty = 3.03

### The 600 mile towing trip:

This trip started on the heel of a brief duty cycle of around town errands and trailer hook-up. The truck was in the dufus zone that I previously described. The trip is about 300 miles, 275 of interstate, 25 miles of back roads. Topography: rolling hills from Atlanta to Columbia (area), South Carolina. The trailer is a 30' car hauler with a weight of 12,000 pounds.

|                   | MPG | Notes                                                                       |
|-------------------|-----|-----------------------------------------------------------------------------|
| On for 20 miles   | 9.2 | Start of trip on interstate at 70mph                                        |
| Off for 204 miles | 9.5 | Continue 70mph interstate                                                   |
| On for 27 miles   | 8.8 | Continue 70mph interstate                                                   |
| Off for 173 miles | 8.7 | Arrived at destination at 20 miles.<br>The return portion of trip 153 miles |
| On for 68 miles*  | 8.7 | Continue 70mph interstate                                                   |
| Off for 45 miles  | 9.4 | Slower traffic as I returned to destination                                 |

### Observations:

- What was it that caused the difference in MPG? A tailwind, headwind, slower traffic, uphill, downhill, or the calculations of the overhead display during the 20, 27, and 68 miles of travel with the regeneration on? My thought, the mileage penalty when the regeneration is on while towing is not significant.
- I made the same temperature observations as I had done for the in-town loop and interstate trip. I had some time to play with the Edge Insight and added two other temperature readings; temperature downstream of the NOx absorber, at the diesel oxidation catalyst (DOC); and downstream of the DOC at the diesel particulate filter (DPF). Here is the chart:

|     | Off  | On(1) | On(2) |
|-----|------|-------|-------|
| EGT | 1200 | 1200  | 1275  |
| Nox | 800  | 1050  | 875   |
| DOC | 775  | 930   | 850   |
| DPF | 760  | 915   | 840   |

(1) The trip east with the wind

(2) the return trip west against the wind

Note: with a digital gauge the temperature is never constant. The numbers I recorded are those that showed when I was able to keep the throttle and EGT relatively constant on level ground.

- Again, I had some time to play with the gauge and watched the relationship of the following display items:

Boost

Fuel pressure

Percent load

Pressure restriction at DPF

If I were a computer geek I could probably find a way to list and chart these four items. However, my common sense-o-meter (and three minutes putting the items on the screen and watching them move in-sync) says that the chart could be drawn using a magic marker connected to the big toe on the right foot.

- What does the \* mean after the 68 mile cycle? It signals two situations that are outside of the limited definition of "normal" that has been thus far established: First, as I had previously noted, the cycles are usually 30 miles or less. Why did the cycle take 68 miles?

Second, in the 68 mile cycle the alarm on the Insight CTS would go on when the regeneration was started. You have to watch the gauge to note the "off" position. In the previous on-off driving cycles I had become accustomed to a number of momentary "offs" and the alarm would let me know of a restart. However, in the 68 mile cycle the alarm went on at least 25 times. I tried to do a correlation to the load factor. Was it at 100% load factor for a length of time that it would go off only to resume operation at a part throttle condition? Why did it not reach the 1100° temperature that I had seen in the in-town or interstate trip travel sections that is noted below in the "On(1)" column of data?

I wish that I had an explanation. I researched Issue 66, page 40 (The Regeneration Story) and concluded the on/off, on/off cycles were controlled by temperature and, since there was not an effect on MPG, I have resolved to realize that there are some things I cannot explain with my simplistic Edge Insight tool and my inability to engineer Cummins' ECU protocol.

### What Do I Recommend?

Well, this should come as no surprise to anyone, after all this is the Ram/Dodge/Cummins Turbo Diesel Register. To quote from last Issue's article where I searched for information to give me "purchase confirmation" about my new 2010 truck, "Nonetheless, for me the most compelling reason for a Ram Cummins win is that the engine and driveline have been in the marketplace for four years and, aside from turbocharger and ECM flashes for emission updates, the engine and drivetrain have proven to be strong and reliable. (There is also the overriding bona fides of twenty-plus years of close cooperation and development between the world's paramount diesel engine maker and Dodge. I shudder to think what problems Ford and GM will encounter as their engines strive to fulfill the 2010 emissions regulations. And with Ford's clean-sheet-of-paper, new engine, well, let me say that their previous 6.4 and 6.0 engines were less than stellar and I would not want to be the guinea pig for this new engine. As Ram/Cummins owners, let's enjoy the three-year head start that we have on the competition."

## Conclusion(s)

In the section “What is the MPG Story” there was a quote from the Cummins engineering group that read, “One has to consider the duty cycle of the truck. If it is being used as intended—moderate to high load in highway travel—the answer is the obvious: the engine’s output of unburned fuel (particulates) is very low, the exhaust gas temperature is high and there is little need to fire-up the self-cleaning oven known as the diesel particulate filter. Consequently the mileage penalty is negligible, if any at all.

“If the truck is being used as a grocery-getter or has long periods of idling there can be an effect on fuel mileage. How much? The estimate is less than 5%. Five-percent is nowhere close to the claims of 5mpg.”

Do my simplistic observations agree with this broad-brush statement?

Let’s take a look at each of the three driving cycles that were presented.

- In-town loop: sorry, I disagree with the assessment “the estimate is less than 5%.” With the new emissions package you had better keep the truck on the highway.
- 700+ mile interstate trip: As noted, there was a marked difference in MPG during a regeneration event. The events happened about 15% of the time the truck was operational.
- 1000+ mile interstate trip: Again, there was a marked difference in MPG during a regeneration event. Driving at a faster speed, the events only happened about 10% of the time the truck was operational. Interesting...

I’m going to look at the 700+ and 1000+ mile interstate trips and try some backward math to determine the “On” mileage penalty or cost.

Here goes:

| 713 Trip as calculated   |                          | 713 Ideal trip           |
|--------------------------|--------------------------|--------------------------|
| 609 miles                | 104 miles                | 713 miles                |
| $\div 16.62 \text{ mpg}$ | $\div 13.78 \text{ mpg}$ | $\div 16.62 \text{ mpg}$ |
| 36.64 gallons +          | 7.54 gallons             | = 44.18                  |
|                          |                          | 42.9 gallons             |

1.27 gallons for regeneration,  $1.27 \div 42.9 = 3\%$  penalty

| 1044 Trip as calculated  |                          | 1044 Ideal Trip          |
|--------------------------|--------------------------|--------------------------|
| 961 miles                | 83 miles                 | 1044                     |
| $\div 15.85 \text{ mpg}$ | $\div 12.82 \text{ mpg}$ | $\div 15.85 \text{ mpg}$ |
| 60.63 gallons +          | 6.47 gallons             | = 67.1                   |
|                          |                          | 65.86 gallons            |

1.24 gallons for regeneration,  $1.24 \div 65.86 = 1.88\%$  penalty

- The 600 mile towing trip: As I noted there were too many variables in my limited 600 mile test. The data is inconclusive and my gut feeling is that there is not a significant difference. Not to mention, do we trust the factory’s MPG display feature?

To close this article, you already know what the author would recommend and the report from Cummins about the engine’s reliability is good. The miles-per-gallon and regeneration stories are a collection of observations by the folks at [www.pickuptrucks.com](http://www.pickuptrucks.com) and from yours truly. And, I’ve given you some advice about town criers, friends, money and how not to run afoul of the EPA. Finally, I’ve provided some insight (Edge Insight, pun intended) into miles-per-gallon and regeneration that helps us define “what is normal/”

Go forth, collect data and let me know what you find. Feel confident in your choice of truck and engine.

**Robert Patton**  
**TDR Staff**

## INSIGHT FROM THE INSIGHT THE COST OF REGENERATION

For the past two issues of the magazine I’ve given you my observations on fuel mileage using the Edge “Insight” gauge package and the truck’s electronic vehicle information center (EVIC) fuel mileage display. As has previously been observed, I used the Insight’s regeneration-on feature as a trigger to reset the EVIC’s mpg monitor and to reset the odometer.

Thus far I have monitored two different types of driving: a total of 1,757 miles of interstate-only/cruise speed 75-78mph no load driving; and 2,415 miles of interstate travel at 67-69mph with a 12,000 pound trailer in tow. For this issue I can add some comments on around town mileage; I can add a 904 mile trip at 70mph pulling a small 4,500 pound trailer (a new category); and 412 additional miles towing the 12,000 pound trailer.

When I started the fuel mileage observations back in Issue 72, I gave these driving loops some names to describe the type of duty cycle. I will use the same descriptive:

Interstate trip (no load)  
Interstate trip towing (4,500-pound load)\*  
Interstate trip towing (12,000-pound load)

\*new category

The following are the data from my observations this past quarter.

### Interstate Trip (No Load)

For this issue of the magazine I do not have any new data. In Issue 72 I did some backwards math to determine the “cost of regeneration” during two, no load interstate trips. The data from these no load trips:

| 713 No-load Trip as calculated                                |                          | 713 Ideal trip           |
|---------------------------------------------------------------|--------------------------|--------------------------|
| 609 miles                                                     | 104 miles                | 713 miles                |
| $\div 16.62 \text{ mpg}$                                      | $\div 13.78 \text{ mpg}$ | $\div 16.62 \text{ mpg}$ |
| 36.64 gallons +                                               | 7.54 gallons             | = 44.18                  |
|                                                               |                          | 42.9 gallons             |
| 1.27 gallons for regeneration, $1.27 \div 42.9 = 3\%$ penalty |                          |                          |
| 1.27 gallons of fuel at \$4 per gallon = \$4.68               |                          |                          |

|                                                                   |                          |
|-------------------------------------------------------------------|--------------------------|
| <b>1044 No-load Trip as calculated</b>                            | <b>1044 Ideal Trip</b>   |
| 961 miles                                                         | 83 miles                 |
| $\div 15.85 \text{ mpg}$                                          | $\div 12.82 \text{ mpg}$ |
| 60.63 gallons + 6.47 gallons = 67.1                               | 65.86 gallons            |
| 1.24 gallons for regeneration, $1.24 \div 65.86 = 1.88\%$ penalty |                          |
| 1.24 gallons of fuel at \$4 a gallon = \$4.56                     |                          |

And now, the total "cost to regenerate":  $\$4.68 + \$4.56 = \$9.64$  for 1,757 miles of interstate travel. To do some further calculations the cost would be \$548 per 100K travelled at \$4 per gallon of diesel fuel or .548¢ per mile.

### New Category – Interstate Trip Towing 4,500-pound Load

This new category is simply the record of the trip that was travelled back in June to the Cummins CMEP Open House event in Columbus, Indiana. It is approximately a 1,000 mile round-trip. The data is presented as follows:

|                 |          |
|-----------------|----------|
| On – 9 miles    | N/R*     |
| Off – 117 miles | 12.3 mpg |
| On – 19 miles   | 11.1     |
| Off – 175 miles | 12.3mpg  |
| On – 8 miles    | N/R*     |
| Off – 57 miles  | 12.0mpg  |
| On – 16 miles   | 10.9     |
| Off – 107 miles | 11.3mpg  |

\*no reading

At this point we arrived at our destination and the truck went into the on-off-on-off cycle that I have described as the "dufus zone." To try and be more professional with my communication, let's officially call this the city driving cycle.

For the return trip we had a change of drivers and it took about 150 miles before the regeneration dinger chimed in and reminded the drivers to collect data for this article. They reached for the note pad and recorded the following:

|                 |         |
|-----------------|---------|
| On – 16 miles   | 11.1mpg |
| Off – 190 miles | 12.9mpg |
| On – 16 miles   | 9.6mpg  |
| Off – 164 miles | 12.3mpg |
| On – 20 miles   | 11.7mpg |

Arrive at destination.

Again, this is not a scientific collection of data, merely an observation using the truck's EVIC mpg feature. And, admittedly, it is a "lazy" observation in that we aren't doing a weighted averaging of the mpg numbers. We just add them up and divide by the number of driving cycles. So, the following are the averages from the data we collected:

Off cycles 6: total miles 810, mpg 12.18  
 On cycles 7: total miles 104, mpg 10.88  
 Percentage of time on 11%, off 89%

For this issue let's do the same backwards math to determine the "cost of regeneration" when towing the 4,500-pound trailer for 904 miles.

The 904 mile, 4,500-pound Towing Trip

|                                                                  |                          |
|------------------------------------------------------------------|--------------------------|
| <b>904 mile trip as calculated</b>                               | <b>904 Ideal trip</b>    |
| 810 miles                                                        | 104 miles                |
| $\div 12.18 \text{ mpg}$                                         | $\div 10.88 \text{ mpg}$ |
| 66.50 gallons + 9.56 gallons = 76.06                             | 74.22 gallons            |
| 1.84 gallons for regeneration, $1.84 \div 74.22 = 2.4\%$ penalty |                          |
| 1.84 gallons of fuel at \$4 per gallon = \$7.36                  |                          |

And now, the total "cost to regenerate": \$7.36 for 904 miles of interstate travel. To do some further calculations the cost would be \$814 per 100K travelled at \$4 per gallon of diesel fuel, or .814¢ per mile.

### Existing Category – Interstate Towing 12,000-pound Trailer

In July I did a short trip with the trailer in tow to Charlotte, North Carolina. The trip covered 412 miles. Putting pencil to paper, this trip was right in line with the previous data that covered three trips totaling 2,003 miles.

Previous data for the 2003 miles:  
 Total miles on, 342 (17% of the time) 9.22 mpg  
 Total miles off, 1,661 (83% of the time) 9.53 mpg

New data from 412 miles  
 Total miles on, 56 (14% of the time) 9.23mpg  
 Total miles off, 356 (86% of the time) 9.65mpg

For this issue let's do the same backwards math to determine the "cost of regeneration" when towing the 12,000-pound trailer for 2,415 total miles.

The 2415 mile, 12,000-pound Towing Trips

|                                                                  |                         |
|------------------------------------------------------------------|-------------------------|
| <b>2003 mile trip as calculated</b>                              | <b>2003 Ideal trip</b>  |
| 1661 miles                                                       | 342 miles               |
| $\div 9.53 \text{ mpg}$                                          | $\div 9.22 \text{ mpg}$ |
| 174.3 gallons + 37.09 gallons = 210.4                            | 210.18 gallons          |
| 1.22 gallons for regeneration, $1.22 \div 210.1 = .58\%$ penalty |                         |
| 1.22 gallons of fuel at \$4 = \$4.88                             |                         |

|                                                                |                         |
|----------------------------------------------------------------|-------------------------|
| <b>412 mile trip as calculated</b>                             | <b>412 Ideal Trip</b>   |
| 356 miles                                                      | 56 miles                |
| $\div 9.56 \text{ mpg}$                                        | $\div 9.23 \text{ mpg}$ |
| 37.24 gallons + 6.07 gallons = 43.31                           | 43.09 gallons           |
| .21 gallons for regeneration, $.21 \div 43.09 = .48\%$ penalty |                         |
| .21 gallons of fuel at \$4 per gallon = 84¢                    |                         |

When you compare the cost of fuel for the ideal trip against the additional cost of fuel during the truck's regeneration events, I noted that the penalty for regeneration is .58% and .48%.

I think this quote has been used once or twice before, from the engineers at Cummins, "If the truck is being used as intended—moderate to high load in highway travel—the answer is the obvious: the engine's output of unburned fuel (particulates) is very low, the exhaust gas temperature is high and there is little need to fire-up the self-cleaning oven known as the diesel particulate filter. Consequently the mileage penalty is negligible, if any at all."

And now, the total "cost to regenerate":  $\$4.88 + .84 = \$5.72$  for 2,415 miles of interstate travel. To do some further calculations the cost would be \$236 per 100K travelled at \$4 per gallon of diesel fuel, or .236¢ per mile.

It makes you wonder how much money the Ford or Chevy owner would have spent in diesel exhaust fluid (DEF or Urea) when travelling 2,415 miles.

On a final note, when towing a heavy load we've seen that it would be \$237 to travel 100,000 miles. One of those fancy programmer units and an exhaust system retrofit will cost you at least \$1,200. So the real cost to bypass the truck's exhaust aftertreatment system: a five year payback; you've lost any rights to warranty consideration; and your truck is illegal, subjecting you to a steep federal fine. Ouch.

### Conclusion

Back in Issue 72 I installed the Edge Insight monitor and started to note the "regeneration on" events and their duration. In Issue 72 I wondered why such a report about regeneration-on events had not been filed since the introduction of the 6.7-liter engine four years ago. I can only assume it was because the previous Edge monitor was also sold with a performance package. And, when the owner installed the kit, likely the emissions aftertreatment components "fell off" the truck.

Regardless of the lack of reporting, I'm pleased to say that data from the Edge Insight has given me the ability to get us to the bottom-line, the total "cost to regenerate," which I noted in the three analysis of driving cycles. The cost was .548¢; .814¢ and .237¢ per mile respectively.

Now, compare these cost-per-mile numbers to the data on page 52 that gives us the DEF consumption that member "Plefever" is seeing with his 4500 series truck. his usage:

1 gallon (at \$4 gallon) for 700 miles = .57¢ per mile or

1 gallon (at \$4 gallon) for 900 miles = .44¢ per mile

Next up, I'm going to try to compare our cost to regenerate to that of the Ford or GM engines and their use of diesel exhaust fluid (DEF).

Does anyone have a Ford or GM buddy with a new truck that has been tracking their use and cost of DEF?

**Robert Patton**  
TDR Staff

### CLEANING YOUR DIESEL PARTICULATE FILTER (DPF) (From Issue 84)

*I have a '07.5 Turbo Diesel and it is equipped with the 6.7-liter engine and the associated exhaust aftertreatment equipment.*

*I'm looking to do some preventive maintenance on my truck at 125,000 miles. How can the do-it-yourselfer clean the diesel particulate filter (DPF)? Would this not be analogous to the grandparents cleaning ashes and soot from their chimney?*

*You can watch video on the internet where folks are shown using water and a Simple Green solution. Likewise, I have been told that brake cleaner works well. However, with the price of a new DPF, I am hesitant to try these shadetree solutions (literally). Are there some proven alternatives?*

*A local diesel shop says that they can clean the DPF at a cost of about \$350. Unlike the grandparents' ashes and soot, there is concern here in California about disposal and hazardous waste. Grandpa and Grandma dumped the ashes in the garden compost. The guys from the video on the web let the black stuff dissolve into their gravel driveway.*

*Any ideas? And, clarification please, on the honeycomb substrate material used in the DPF.*

**William Westwood**  
Sonoma, CA

William asked, "Any ideas?" You bet. First, admit that I don't know the answer and ask for some help from Cummins.

The really short answer: whether it be the '07.5-'12 truck that uses diesel fuel to lightup and regenerate the diesel particulate filter (think to yourself, self-cleaning oven), or the '13-'14 trucks that inject urea into the DPF, the DPF should *never* have to be removed for cleaning. That's right, never.

I know, you find that answer to be suspect, after all we all know, have read about, or have experience with the "Diesel Particulate Filter full" message on the overhead display.

I vividly recall the introduction of the 6.7-liter engine in January of 2007. And, should you want a history lesson on Cummins, big oil companies, the EPA, ultra low sulfur fuel, and this engine's early introduction to the marketplace (it met the 2010 emissions guidelines), you'll want to reread Issue 78, pages 52-53.

Back to the story: the introduction in January 2007. The product launch had its share of teething problems. Cummins and Ram had a series of reflashes to update the engine's control of the exhaust aftertreatment. Cummins and Ram put together a DVD with TDR writer Sam Memmolo as the host that discussed the engine's aftertreatment. The video dispelled the buzz of misinformation about the engine. The bottom line—use the truck like a truck. At the time, putzing around town was causing too many of the bells and whistles to sound. Over time, and with the approved reflashes to update the controls, the engine has settled down and warranty

numbers are lower than they have ever been. (Really, lower than the great '03-'07 engines, lower than 12-valve engines. This isn't marketing hype. It is from the blue-collar folks at the plant, CMEP, whose job it is to track the numbers.)

Okay, let's get back to the short answer of "never" and the long, long answer to William Westwood's inquiry.

Before calling Cummins I did the same research as William and found the same internet videos that show a liquid-type DPF clean-up. Realizing that Cummins is so much more than a 6.7-liter engine in a Ram pickup, what were/are their thoughts on liquid clean-up? Remember now, they've seen it all: from big rigs to construction equipment to generator sets. The answer: DO NOT use a liquid or brake cleaner as a clean up method. The concern is the ash mixed with a liquid can form a paste that, considering the tight tolerances of the DPF's honeycomb grid, when finally dry would render the DPF clogged and useless.

Again, realizing that Cummins is so much more than the 6.7-liter engine in the Ram pickup, I asked what was happening elsewhere in the industry and would they please help me relate the answer to William Westwood's "clean the DPF for \$350" chimney sweep findings.

I went back to the internet and found several manufacturer-type and service organization-type videos to watch. The \$350 "clean it" involves removal of your DPF; mount the DPF in an enclosed chamber; affix inlet and outlet collars to the DPF; and then blow high pressure air through the DPF. A phone call to my local Cummins distributor confirmed that that's the way they do it on the big rigs. And, the TDR audience should realize that the big rigs have a problem with ash build up in their DPFs. The ash is caused by lube oil that is burned as it escapes past the piston rings. With the 6.7-liter engine in the pickup the only problem is soot and the soot is cleaned in the regeneration process.



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**Yes, they make cabinets that will heat and pressure clean DPFs to clean them if they are contaminated with lube oil or coolant from a fouled engine.**

So, this brings us back to the original short answer from Cummins—the Ram's DPF should never have to be taken off for cleaning. (Our engines do not suffer from oil consumption problems.)

## SIDEBAR

### IS THERE A DIFFERENCE FOR THE 2013-2014 TRUCKS?

If you read the article closely, the '13 and '14 trucks were discussed in my opening remarks to William (second paragraph) and the DPF should never have to be removed for cleaning.

End of conversation?

Not so fast.

As it turns out, the DPF used on '13 and '14 trucks is a bit different than that used in the '07.5-'12 trucks. When I discovered this, I immediately (logically?) made the assumption that the change was made to allow the use of urea with the DPFs self-cleaning oven. Not so.

For the 2013 and now 2014 trucks the material used inside the DPF is made of silicon carbide (SiC). The previous '07.5-'12 DPF used a material known as cordierite.

The new SiC cores are more expensive than those made of cordierite. However, the smaller packaging area of the 2013-2014 truck's undercarriage required the use of the more expensive SiC core. As a side note, I did learn that the SiC core also has a higher melting point than the cordierite core. The higher melting point gives the DPF a bigger cushion should there be unplanned problems with the aftertreatment or over-fuelling. The SiC units melt at approximately 1700°, the cordierite at approximately 1250°.

So, yes, there is a difference in the material used inside the DPF. However, the change was not necessarily related to the use of urea in the exhaust aftertreatment.

## THE 800 POUND GORILLA (From Issue 84)

With all of this discussion about DPFs and clean-up of the system I sense that there is a question that has yet to be addressed. The 800-pound gorilla in the room has a question. On the gorilla's behalf I'll type in his query: "Why not just ditch the aftertreatment system?"

The simple answer: it is illegal to do so.

In the day-to-day operation of this magazine and the TDR's web site, as well as general oversight of the TDR's writers and staff at Geno's Garage, the response of "It is illegal to do so" is often met with angst and anger. We all understand the economics of aftertreatment maintenance weighed against the responsibility to do the right thing.

William Westwood's "clean the DPF" letter was received just after my article "Diesel Performance Update" was written in last issue's magazine. The "update" article shared with you the story about the broader reach of the EPA to stop the sale of ditch-the-aftertreatment products. Because of emissions testing and inspections at the local or state level, the ditch-the-aftertreatment concept is not a consideration.

However, I can explain this, the writers can explain this, the Geno's Guys can explain this; and we are still met with resistance and an occasional outrage or two.

Collectively, the best we can do is explain the situation and point the owner back to a two page article that was written in the TDR 1.5 years ago when some of the first '07.5 engines/trucks were officially out of the emissions and engine warranty period and owners were looking for alternate answers.

I hate to do a reprint but, aside from the further legal enforcement that I discussed last issue, nothing has changed. And, as witnessed by William Westwood's inquiry, this question is an almost daily occurrence. Here is the data from Issue 78:

### AND WE'RE OFF TO THE RACES (Time to Ditch the 6.7-liter's Exhaust Aftertreatment System?)

With a title like "Off to the Races" one might assume that I had just returned from a trip to the Kentucky Derby.

Not so, I was simply having fun using the dictionary of idioms and phrases, searching for an expression that best describes a press release sent to our offices **in the summer of 2012**.

**The product:** a new "Atlas Exhaust System" is designed for the '07.5 and newer Ram/Cummins trucks with the 6.7-liter engine. Although not mentioned anywhere in the press release, close examination of their Atlas system reveals that the kit is a direct bolt-on (turbocharger back) aluminized steel pipe and muffler. Pipe and muffler—that's it.

Oops...what happened to the exhaust aftertreatment devices: the diesel oxidation catalyst; the nitrogen oxide adsorber; and the diesel particulate filter? Careful examination of other exhaust system web

sites (and I mean careful), shows that an owner can piece together a turbo back, non-aftertreatment, non-legal exhaust system for a 6.7-liter engine. But none are so bold as to offer a single part number kit for such a product.

Perhaps a better idiom for this article: Open the Floodgates. "To allow water that had been held back to flow freely." Or, "If an action opens the floodgates, it allows something to happen or it allows many people to do something that was not previously allowed."

Oops...as the editor, I'd better be careful using the second idiom. Let's be clear, the idiom says, "to do something that was not previously allowed." Removing the 6.7-liter's exhaust treatment components is not allowed, nor will it be allowed, subject to a penalty and fine from the EPA. (Section 205 of Clean Air Act: Penalty of up to \$25,000 per day for violations.) The chapter and verse from the TDR where we have covered the subject: TDR's Turbo Diesel Buyer's Guide, pages 70-75, has the complete story.

So, is that the end of this correspondence? The editor stumbles across a press release; finds some cute idioms to make his point; cites the vendor for irreverence; identifies the reason that you should not consider the product; and then closes the story?

Well, perhaps that is where I should stop. However, to brush aside the rest of the story would prove—once and for all—that I am akin to the three wise monkeys: see no evil, hear no evil, speak no evil.



The following is an example from web site correspondence of how innocently the subject of the exhaust system delete comes up:

Can someone tell me if you can cut off the entire muffler system on a '07.5 truck? Will it start if you do it? If you can do it, who does it so I can get mine done? Has anybody else done this? If so please show pictures if you have them. Where I live we don't have emissions. My truck runs like crap.

**Mr. Newbie**

If you are asking if you can just delete the exhaust emission components, the answer is no. You have to do a downloader, like Smarty or H&S (an alternate engine program) to get the truck to run correctly without the emission components.

**Mr. Experience**

Legally a company cannot remove the aftertreatment system and replace it with standard pipe, it is a federal law. However, if you do remove the aftertreatment system DPF, then you'll need a programmer to turn off the sensors. You also will want to check your state for local emissions testing.

**Mr. Caution**

I'm not in California. Okay, so let me see. In order to get the truck running right then, I need to buy and install an alternate engine program? Have you ever installed one of these systems in your truck?

**Mr. Newbie**

I have the Smarty J67 (stock programming) on my truck. To do the DPF/EGR deletes you'll need the J67-ME. The Smarty plugs into the OBDII port and then you select which programming you want to download. As I understand it, ME stands for a program used in Middle Eastern countries that ignore the unplugged sensors. It takes about 3-4 minutes.

**Mr. Been There/Done That**

Cool, dude! I can delete the system, add a programmer and experience all the great things I've read about at all the diesel web sites: better performance and better miles per gallon.

**Mr. Newbie**

Not so fast. Remember the fines that you are subject to and you might want to reconsider those great "claims" you've heard. Our magazine's Editor had a close friend that tried it on his '07.5 truck. I strongly suggest you read Issue 72, page 34. The results on MPG were nowhere near as substantial as others would have you believe. If I recall correctly, the owner had problems at 35K miles with a regeneration when there was nothing to regenerate into. And, depending on the manufacturing date of ECM, you may have difficulty doing a program update (TDR Issue 65, page 42, "Secure bootloader software, or boot").

**Mr. Caution**

Sorry, man. It's my truck and I'm going full speed ahead. I'll even put the junk back on my truck should I need some warranty.

**Mr. Newbie**

Not so quick, Mr. Newbie. You've just described the definition of FRAUD. I suggest you realize that you will be driving an illegal truck and that you are your own warranty station. You stated, "It's my truck," and you've been forewarned of the consequences of the modification. Accept responsibility and go ahead and do what you need to do.

**Mr. Caution**

A final story to consider:

Where I live we've seen customers delete the aftertreatment components and then come in to trade their truck. Imagine their surprise when we tell 'em the value is \$2500-\$3000 less than if the equipment was on the truck. They have to have us reinstall the hardware or we can't take it in trade.

**Mr. Texas**

## Conclusion

If you do a web search on "EGR delete," "6.7-liter programmer" or "DPF delete" you'll find that there are hundreds of posts, threads and conversations that discuss these topics. I have done my best to caution against tampering with the emissions controls. And, until the press release by aFe, I've followed the mantra of three wise monkeys; see, hear and speak no evil.

Truthfully speaking (would you expect anything but the truth?), you've not seen *any* performance upgrade articles in the TDR about the 6.7-liter engine. And, considering the warranty, legal, and drivability implications there really is nothing to report. I'm still looking for the first vendor to send me a press release touting their new CARB Executive Order number (proof of continued low emissions) demonstrating that their accessory meets the guidelines.

Looking long term, could this hurt the TDR? Well, we've lived through almost **eight** years without turbo-gizmos, injector-whizzes or tuner stacks and jacks, and, again, I really don't see any products of this nature coming down the pike. Yes, I know folks tweak the 6.7 and, if there is a positive to all this rambling, unlike the years prior to the 6.7-liter engine, those that tweak are assuming the responsibility of being "their own warranty station."

Would I like to see some factual reports about performance and fuel mileage? Without a doubt. However, who is going to put their name on an article in which you tell the world, "Come check out my truck and send me a \$25,000 fine?"

**Robert Patton**  
**TDR Staff**

## Epilogue – Why Then, But Not Now?

When I gave this issue's "Technical Topics" to the staff at Geno's Garage for review, the feedback I received was, "Wasn't/isn't the 5.9-liter engine owner subject to the same EPA fines that are discussed in the article?" And "Why did the TDR talk about performance prior to the 6.7-liter engine, but not now?"

The answer(s), "yes" and "but." (I really wanted to say, "Go read the [TDBG](#), pages 90-95.)

More on the "yes" answer: Yes, an owner is subject to the strict \$25,000 EPA fine if caught tampering with the emission control devices on his truck. However, and this is a big "however," the way I see it is that the EPA has much bigger fish to fry than an individual that modifies his truck or automobile.

If I were from the EPA, the first place I would go to crack down on non-compliance would be to the Walmart magazine rack and pick up the latest copy of Diesel-This-and-That. Turn to any page and you'll see the advertisement for "BlackSmoke.com's" latest Ford, GM or Cummins EGR delete kit. Turn to the next page and you'll see the advertisement for an ECU programmer. **(Update 2014: No longer do the ads thumb the authorities.)**

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More on the “but” answer: Looking at the big picture, prior to the 6.7-liter engine, but more specifically the 1/1/2007 emissions legislation date for all the manufacturers, there was not a central meeting or gathering of the aftermarket and EPA officials. Since 1/1/07 the aftermarket cannot say that the EPA has not given out dire warnings. The aftermarket cannot say that California's Air Resource Board (CARB) hasn't issued strict guidelines. The big meeting where the announcements about “look the other way” prior to 1/1/07 and “we intend to enforce” after 1/1/07 occur each year at the Specialty Equipment Market Association's (SEMA) meeting that is held in November. We have written about these meetings several times in the TDR. The reference location for dialog from previous SEMA meetings: TDBG, pages 70-75. It is a long and twisted story.

Further, looking at the big picture, emissions tests are done on a state by state and, in the case of my state, local region (a metropolitan city) by local region basis. These state emissions testers don't have a hot line to the EPA, they just do their job and send folks home to “clean up their act” if they do not pass the local test criteria. If my assessment of the emission test is different from what prevails in your state, please let me know.

So, with the exception of California and a handful of other states, there is not a steadfast emissions check criteria for engines/trucks prior to 1/1/07. I've attended the SEMA meetings. The editorial staff has heeded the EPA's warnings.

***Update 2014: As reported last issue, pages 44-48, the EPA has started investigations into the wholesale distribution system. The EPA wanted data on where the parts were being sold. Watch out small shops? Magazine ads have been “cleaned up” (literally). However, sales of tuners still happens through a number of internet sites; most with foreign business addresses.***

***Rumor has it that an investigation of a wholesale distributors's records led the authorities to a shop location in the northeast area. A site visit was done and the shop owner paid a \$4,700 fine and lost his “dealer” status for six months. The shop was fortunate in that he did not have to open his books to tell who/what/when/where about his end customer and whether the customer was truly off-road racing.***

Robert Patton  
TDR Staff