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UNDERSTANDING AIR INTAKE SYSTEMS
PART TWO (AIR DENSITY)
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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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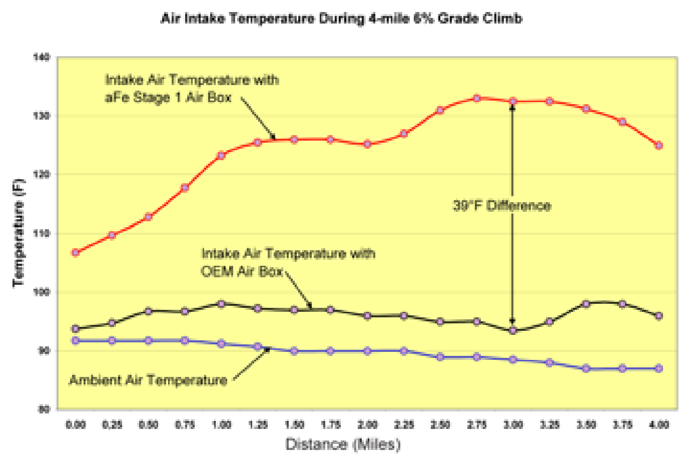
HOW AIR INTAKE TEMPERATURE EFFECTS POWER

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

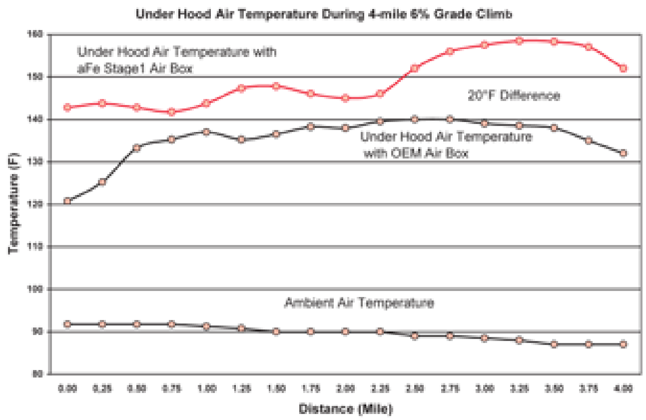
Is there any validity to the idea that cooler intake air results in cooler exhaust gas temperature? If so, how much? The 6% grade testing concluded that for every 1° of cooler intake air, the EGT is reduced by 1.5°. Mark Chapple at TST Products has performed similar testing and has determined that 1° 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.

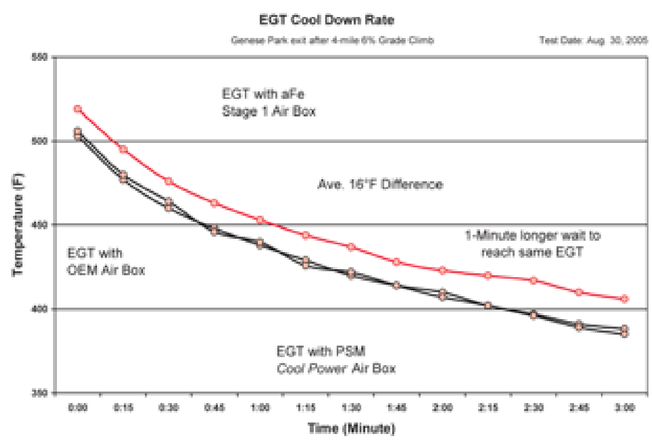
- Increase fuel mileage: Rule of thumb is that every 10° drop in intake air temperature should increase fuel economy by 1%. This small mileage increase is impossible to accurately measure in real-world testing as there are larger variables that affect fuel mileage.

- 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!

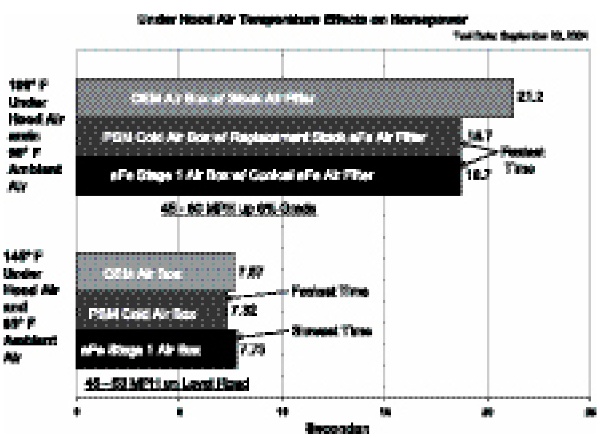
Testing a vehicle on a dynamometer is similar to running a laboratory test, where environmental conditions and test procedures are optimized to produce the most power from the vehicle. Typically the hood is up to vent engine compartment heat away from the engine. Raising the hood may allow the air filter 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 86° Intake Air			Hood Closed 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:

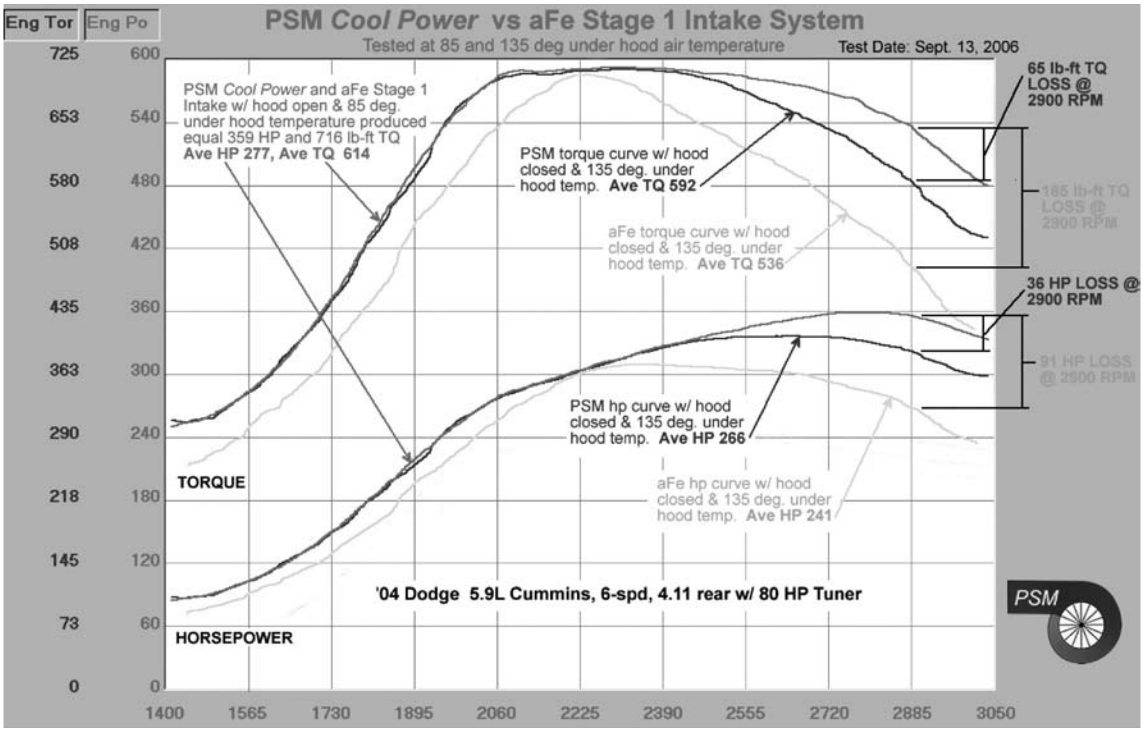
1) Removing the air snorkel between the air box and fender or using an open conical type filter resulted in lower power numbers because hot under hood air was allowed to enter the intake. This is true whether the hood was open or closed.

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.

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Vendors/Suppliers and Manufacturers Mentioned

Advanced Flow Engineering (aFe)
191 Granite St.
Corona, CA 92879
951-493-7100
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ATS Diesel Performance
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