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PRODUCT SHOWCASE

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

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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.

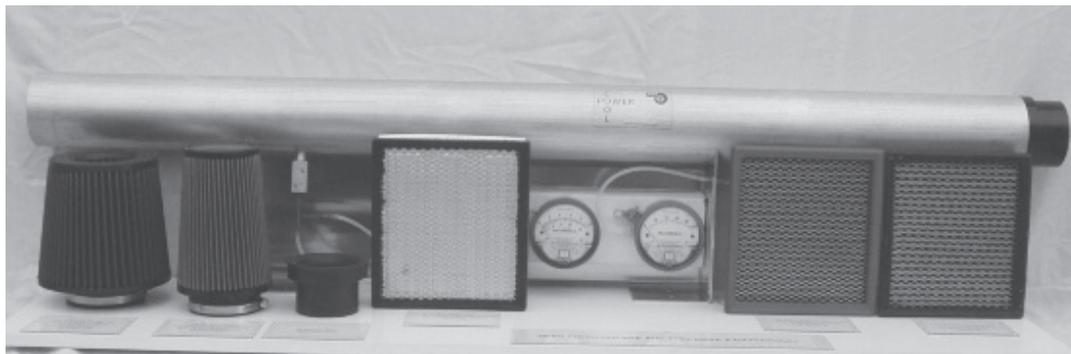
Although we did limited testing on the Amsoil Ea filter, it appears the stock Mopar and Amsoil Ea nano-fiber filters provide the same performance. They both enhanced low-end torque below 2000 rpm and relinquish some top end power to the other filters tested. However the two to three horsepower loss above 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.

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.



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

Air Box

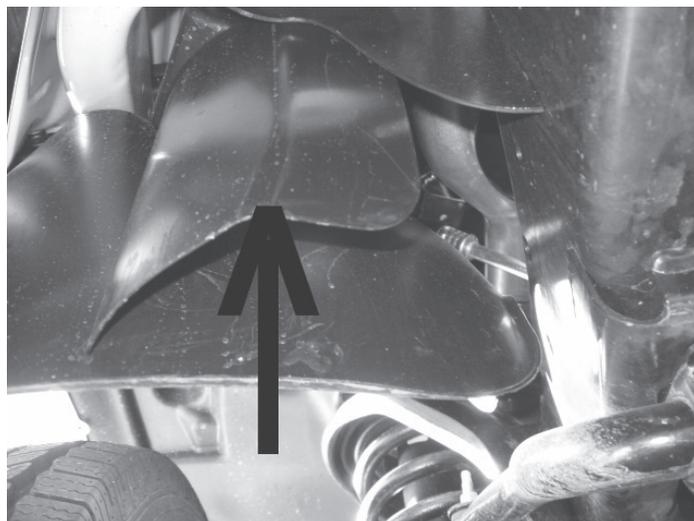
The three air boxes we tested were the stock '04 unit, a Performance Systems Mfg. (PSM) modified stock air box with an inlet duct running from the bottom of the air box to the underside of the vehicle, and an aFe semi-heatshield type open metal box.



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.

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



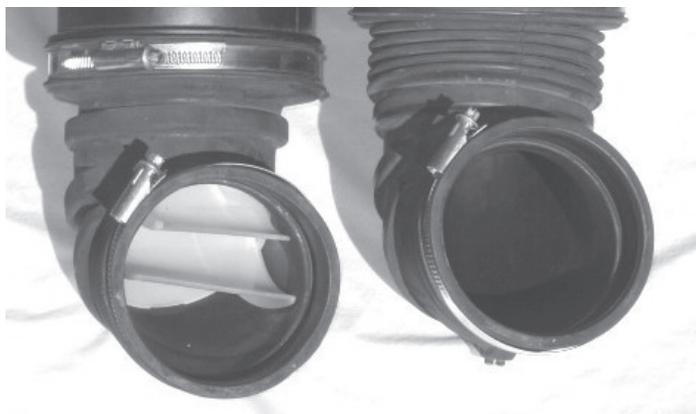
Arrow pointing to vertical baffle used on '04.5 and newer trucks to keep under-hood heated air from entering the air box

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.

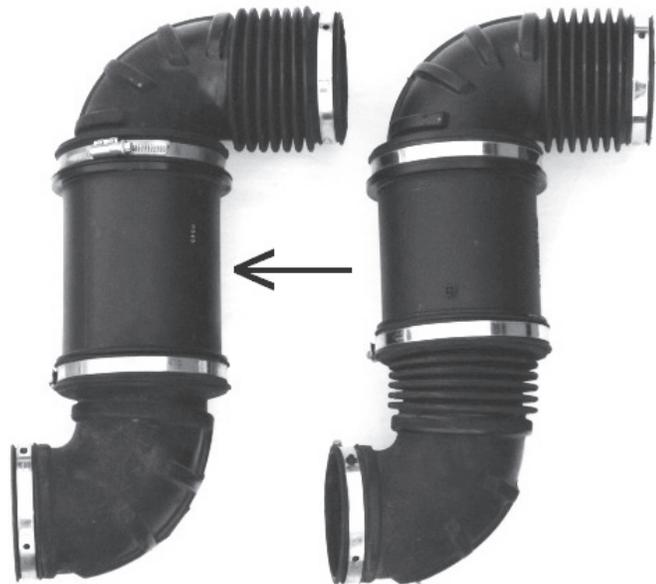
Intake Tubes

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		16	+3.6	+2.5
3	-2.0	+0.4	Filter	14	+2.8	+1.4
2	+6.1	-2.5	Air Box	15	+5.8	+1.7
	+5.1	+1.1	Tube		+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.

STOCK FUELING

DYNAMOMETER SUMMARY CHART

Test	Max Boost	Torque@1800 RPM	Max Torque @ approx. 2250 RPM	Pressure Drip @ 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 cm² exhaust housing to a 14 cm² 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.

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.

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Vendors/Suppliers and Manufacturers Mentioned

Advanced Flow Engineering (aFe)

191 Granite St.
Corona, CA 92879
951-493-7100
www.aFefilters.com

ATS Diesel Performance

5293 Ward Road
Arvada, CO
800-949-6002
www.atdiesel.com

Diesel Power Magazine

www.dieselpowermag.com

Performance Systems Mfg.

17464 W. 43rd Drive
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