The Performance Professor

Jim McFarland

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Exhausting Systems

Introduction

Improper evacuation of combustion byproducts can lead to lost power, fuel economy and overall vehicle performance. A fundamental understanding of the exhaust process can help lead to improved engine efficiency.

With all the current interest in providing engines with properly timed, correctly conditioned and rpm-related air/fuel mixtures, focus can be lost on the importance of efficient cylinder evacuation. As pointed out in an earlier n2performance.com lecture, internal combustion engines are surrounded by atmospheric pressure, externally acting on both the intake and exhaust system. Despite there are times when atmospheric pressure is higher than cylinder pressure, the ability of exhaust gas dynamics to effectively remove unburnable residue is key to high percentages of fresh mixtures and power.

The following discussion contemplates many of the major areas of engine component design and function that relate to an efficient exhaust system. The subject of mufflers is being withheld for a future lecture. There's sufficient exhaust system material to review that does not include these parts. This approach will also make it easier to tie mufflers into the overall system, once that discussion unfolds.

Basic Information

The exhaust "problem"

Simply stated, exhaust gas will not "burn a second time." It also occupies space, so its removal from an engine's cylinders is necessary to achieve good combustion efficiency, following the successive induction of fresh air/fuel mixtures. The "problem," if you will, amounts to creating a set of conditions whereby the greatest possible quantity of combustion byproducts (exhaust gas) is removed from the engine. Unfortunately, the "problem" is never completely resolved, even in the best of cases. But the objective is still to achieve the highest degree of evacuation obtainable from firing cycle to firing cycle.

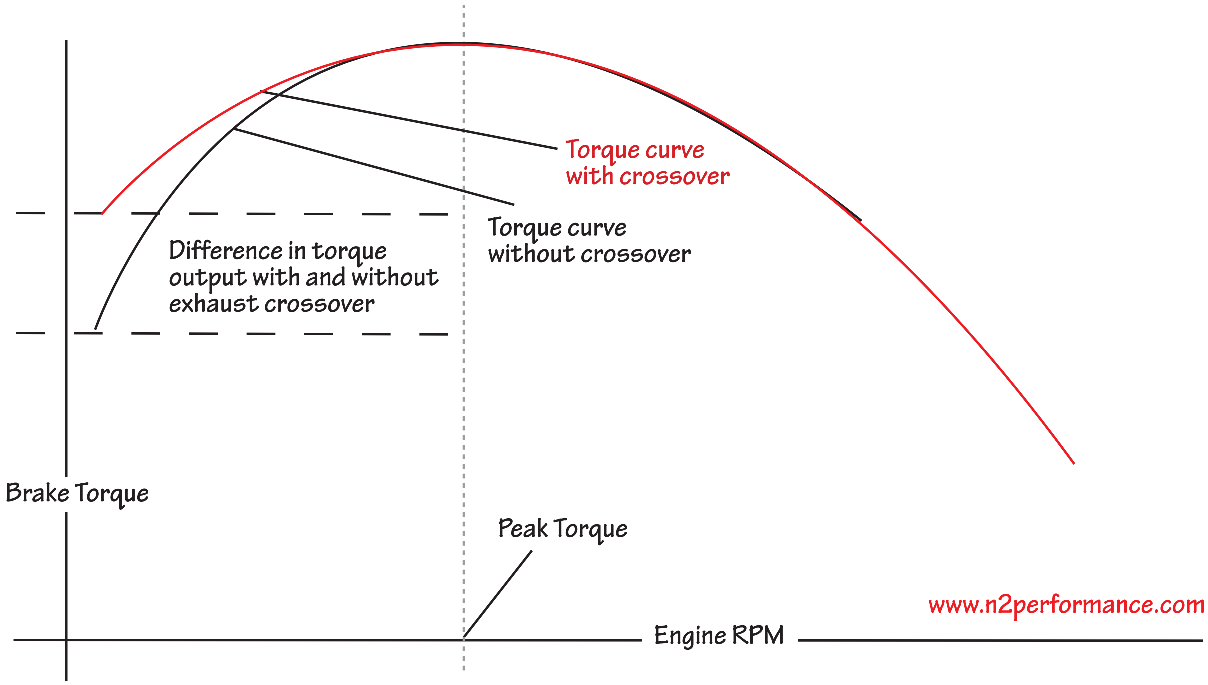
Purely from the standpoint of air pollution, exhaust gas that remains in an engine's cylinders tends to reduce combustion temperature. Of the combustion byproducts that pertain to emissions concerns, oxides of nitrogen (NOx) is heat related. By the reduction of combustion heat, a corresponding reduction in oxides of nitrogen can be accomplished. Exhaust gas that is intentionally put back into an engine's cylinders, especially during times of high heat production (engine under load or experiencing increased power output), is called "exhaust gas re-circulation" or EGR. The introduction of EGR is regulated by a vacuum- or load-sensing device that opens or closes a valve directly connected to the engine's exhaust system, typically from a passage in the intake manifold that is provided exhaust gas.

From the standpoint of combustion efficiency, EGR is a deterrent to power and fuel economy, although of emissions benefit. Depending upon the efficiency of an engine's overall exhaust system, some amount of "residual EGR" can also reduce power and economy. So in cases where outright power (and/or fuel economy) is the objective, optimizing combustion byproducts removal is necessary.

Exhaust gas evacuation

Consider the sequence of events leading up to and during the removal of combustion byproducts. During combustion, cylinder pressure rises to its highest value, turning this pressure into work done on the pistons, which results

Comparison of Torque Curves with and without Exhaust Crossover Pipe



Note: In much the same fashion that a header collector "works" below and up to peak torque rpm, crossover pipes provide gains in a similar range or engine speed. If an engine is carbureted, the addition of a crossover typically requires a change to enrichment.

in turning the crankshaft. At the time of exhaust valve opening, a burst of exhaust gas passes into the exhaust port and remaining portion of the exhaust system (exhaust manifold, muffler, pipes and catalytic converter, if one is present). This period is called the "blow-down cycle" portion of the complete exhaust cycle. As blow-down continues and gas flows from the cylinders, pressure drops and net flow decreases until the exhaust valve is closed. Highly simplified, this is the process during which exhaust gas evacuation takes place.

Of the elements used to create efficient exhaust gas evacuation, timing the exhaust valve opening point (relative to piston position), exhaust port design and flow capability, and the ability of remaining exhaust system components to establish and maintain adequate flow rates are key.

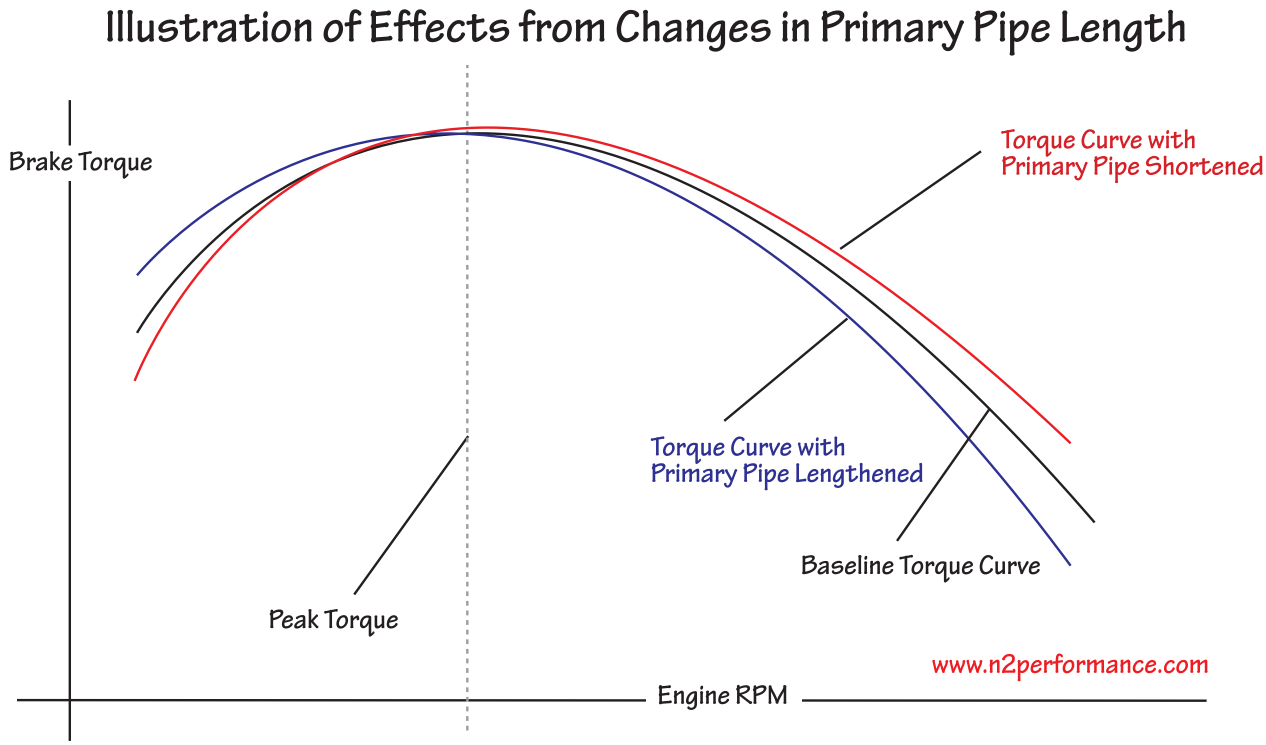
Exhaust backpressure

During the process of exhaust gas evacuation, it is possible for pressure in the exhaust system to rise above the point that allows efficient gas flow. This condition can be caused by a restrictive system component (typically muffler or catalytic converter), improperly designed system element (exhaust manifold, cylinder head port, ducting or pipe) or an engine that has been modified for increased inlet air flow (higher power output) or rpm.

In any case, this condition of "backpressure" causes a corresponding increase in combustion byproducts residing in the cylinders. As previously discussed, this leads to reduced combustion efficiency by the presence of un-burnable elements (exhaust gas) in the engine's cylinders. Backpressure can also have a mitigating effect on exhaust note (depresses sound), but this will be discussed in greater detail in the upcoming lecture on mufflers.

Backpressure is also affected by piston displacement and engine speed. For example, at any given rpm, as engine size is increased so is the total volume of air the exhaust system is required to handle. Even at the same piston displacement, backpressure accumulation is a function of rpm; the higher the rpm, the greater the potential for exhaust system backpressure. Unless changes are made to an exhaust system, consistent with displacement increases or elevated rpm, a specifically sized set of exhaust components can appear gradually "smaller" to the engine.

Interestingly, during low rpm operation, some amount of backpressure can be of benefit to power. Aside from the dilution and



Note: Since peak torque rpm (as affected by the exhaust system) is largely determined by primary pipe area, lengthening and shortening primary pipes tends to "rock" the baseline torque curve about this point.

power loss this can cause, residual pressure in the exhaust system can prevent fresh air/fuel charges from being "drawn" from the cylinders during valve overlap. In this case, the term "drawn" is a misnomer. Actually, it is during this period that pressure in the exhaust path can become lower than inlet pressure, allowing atmospheric force to "push" fresh mixtures into the exhaust system. Up to the point where backpressure becomes a cause of combustion contamination (primarily a function of rpm), so-called "over-scavenging" can be prevented or reduced by the presence of low-level backpressure.

Stock exhaust manifolds

Until growing concerns for exhaust emissions reductions and increased vehicle fuel economy (especially Federally-mandated Corporate Average Fuel Economy or CAFÉ standards) arose in the 1970s, the majority of stock engines had "log-type" exhaust manifolds…typically made of cast iron. But as engine and combustion efficiency became critical OEM design issues, exhaust manifolds took on changed functions and appearances.

Cast iron exhaust manifolds now contemplate the needs of each individual cylinder's exhaust path. More cylinder-to-cylinder "separation" is evident in today's cast iron manifolds. In many instances, there is more length to these separated paths…providing more path separation than exhaust tuning.

On the other hand, some OEMs have elected to design manifolds that appear more like high performance "headers," consisting of primary pipes with a measure of tuned length, even if traditional high performance collectors are not included in the package. Most of these types of stock exhaust manifolds have been introduced on the higher performance OEM engine packages, in an effort to increase net power but not at the expense of emissions or fuel economy potential. Any weight savings, cast iron to stainless materials, has likely had negligible effect on fuel economy tied to gross vehicle weight. But if you think an OEM-type exhaust system is of little value to an overall engine package, glance under the hood of the next import vehicle you spot.

Modified exhaust systems

If backpressure is considered undesirable, in the majority of conditions, various methods can be employed to reduce its presence and impact. "Splitting" a stock exhaust or installing "dual" systems (regardless of the number of engine cylinders) is a time-honored approach. The simple addition of a less restrictive (total) exhaust path will reduce backpressure, particularly as engine size or rpm is increased.

If an existing system is already of dual design, installation of "larger" pipes and/or mufflers will further aid backpressure reduction. Of course, the use of headers or comparable low-restriction exhaust manifolds will further aid exhaust gas flow. Installation of a "crossover" pipe (to be discussed next) is an additional method by which total backpressure can be reduced.

As in the case of most engine modifications, pinpointing the rpm range in which the engine will be most frequently operated is a fundamental yardstick in the planning process to obtaining performance objectives. This axiom certainly holds firm in the area of exhaust system changes.

Primary pipes & collectors

The simplicity of this subject almost defies belief. Remember, that an exhaust (and intake) system can be "tuned" separate of each other. Taken to extreme, each will produce its own "torque curve." Keep that in mind as you read the following.

Basically, primary pipe diameter determines the rpm point at which a torque boost (peak) will be produced. Since peak torque points are associated with specific flow rates in the primary pipe and flow velocity is a function of pipe section area, pipe diameter determines peak torque rpm. This rpm point then becomes the "fulcrum" about which the torque curve pivots as changes in pipe length are made. Rule of thumb? Lengthen pipe to add torque above the peak and remove it from below. Shorten pipe length and the opposite occurs.

Collectors function below peak torque. Operate an engine above peak torque and, all else being equal, a collector is unnecessary. Operate an engine to include rpm below peak torque and collectors can be quite valuable.

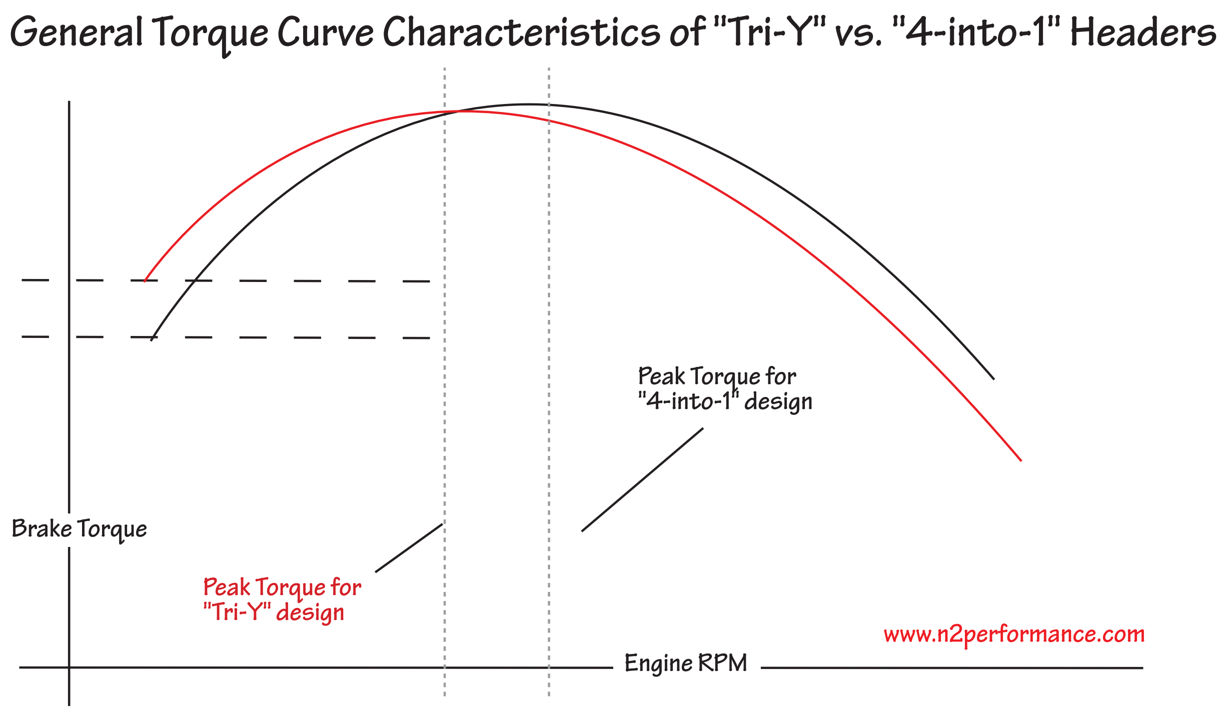
That's simplified, but that's it.

Crossover pipes

Currently the subject of testing and discussion within the automotive performance community, the joining of two head-pipes appears a worthwhile modification. In fact, certain "theories" are being banded about with respect to why crossover pipes do anything. While it's not the purpose of this particular discussion to advocate one method or another, it is our charter to present salient points for you to consider…pursuant to forming your own opinion.

Since crossover pipes, independent from design, are placed ahead of an exhaust system's mufflers, pressure accumulation ahead of the mufflers is presumed reduced. Data supports this belief. Based upon an engine's firing order, the rise and fall of pressure in the pre-muffler pipes does not follow a uniform, evenly spaced pattern…side to side. So the joining of head pipes provides at least an opportunity to alter the effects of these pulsations on the net of exhaust system flow.

If that appears to be too complex, think of it this way. Each side of a dual exhaust system does not receive an exhaust "pulse" at each successive crankshaft firing position. For example, if the firing order happens to be 1-8-4-3-6-5-7-2, a typical 4-into-1, collected exhaust system would deliver successive pulses (5 and 7) every complete set of firing cycles…instead of alternating bank-to-bank for each cylinder in the order. Consequently, the use of crossover pipes (in varying designs) can have an effect on the effects of



Note: Although somewhat exaggerated, these two torque curves depict basic differences in characteristics between a typical "Tri-Y" design and a "4-into-1" layout, as applied to a V8 engine. Depending upon primary pipe sizes, the two may exhibit different peak rpm points, but the ability of a "Tri-Y" to increase low rpm torque is typical, as compared to the "4-into-1" design.

"out-of-sync" exhaust pulses, smoothing out net flow and offering the potential for small power gains…which is about what can be expected in best-case uses of crossover pipes.

Reversion

This topic will be discussed in greater detail in the Advanced Information section, but there are some basic comments appropriate at this point.

In a previous N2Performance lecture, it was pointed out engines operate with atmospheric pressure (unless under supercharged conditions) at the intake and exhaust entry and exit points, respectively. Stated another way, atmospheric pressure acts to force air into an engine and must be overcome at the end of the exhaust pipe.

Therefore, we must examine the conditions within the cylinders that cause pressure to rise and fall, during the various intake / compression / power / exhaust cycles. This is important to understand because there are times, based on valve timing, when atmospheric pressure can (and does) influence cylinder pressure. This is most often during valve overlap when both "sides" of a cylinder (intake and exhaust) are exposed to atmospheric pressure.

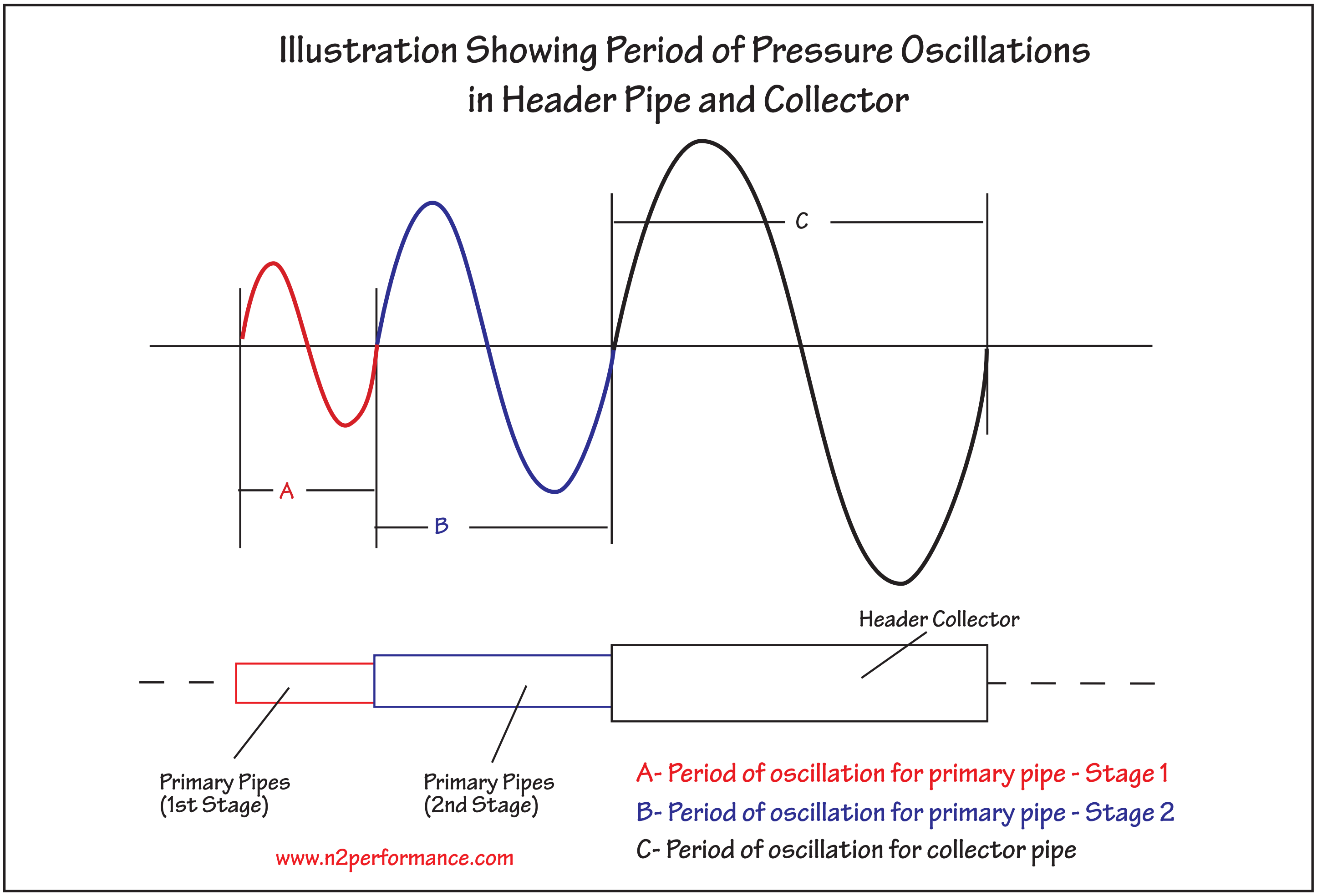
One reason for this understanding is to recognize that during times when atmospheric pressure is higher than cylinder pressure, exhaust gas can be forced back into the combustion space, causing dilution of subsequently fresh air/fuel mixtures. Such reverse flow (or back flow) has been labeled in several ways, often called "reversion." And since we know the presence of exhaust gas in the combustion space can lead to power loss, reversion is not considered good for optimum engine performance. As indicated, the remainder of this discussion will be presented in the Advanced Information section.

Advanced Information

Put on your "smart" hats. We're going to load you up this month. Let's go back to the discussion about the exhaust "problem" and look a little deeper into its elements…including valve timing, piston motion and port design. These are interrelated topics, with respect to solving the exhaust problem. But let's take them one at a time.

Valve timing

Visualize an engine package that includes a mechanical tappet camshaft. This will enable us to "adjust" valve timing by changing valve lash settings. In order to keep things simplified, let's focus only



on the exhaust side of the cylinder. We run the engine and measure system backpressure and power level. By making an incrementally small decrease in exhaust valve lash, we effectively increase duration of the exhaust event. A re-measurement of backpressure and power shows a pressure reduction and slight power increase, primarily at the higher rpm. Were we to make an additional reduction exhaust valve lash, chances are we'd observe a further reduction backpressure, a decrease in low rpm power and a further increase in power at high rpm.

So what's the point? Changes in valve lash are analogous to changes in valve timing, in this case duration. By changing valve timing or "duration," we saw immediate changes in both backpressure and power. Clearly, then, valve timing is linked to exhaust system backpressure and power output within specific ranges of rpm. The corollary to this is that we can correspondingly affect backpressure and power within specific ranges of rpm by changes to exhaust system components.

Both these types of adjustments (changes to valve timing and backpressure) affected the common denominator to making overall power; volumetric efficiency. Recall from previous discussions that v.e. is linked to torque (the independent variable) from which horsepower is calculated (the dependent variable). We have finally come to a point in the development of n2performance.com's series of Performance Professor "lectures" where the process of fitting presumably separate subjects into a completed picture. As these lectures progress, you will discover more such links.

Now, let's examine the effects of piston motion on backpressure… and how it relates to exhaust system function.

Piston motion

If the rate at which a piston traverses its cylinder affects pressure in the exhaust system, which it does, then how so? We already know a relationship exists between piston motion and valve timing. During the exhaust stroke, a piston moving rapidly will rely less upon efficiency of an exhaust system than one moving more slowly. The slower it moves, the more reliant it becomes on flow efficiency of the downstream exhaust path. These two conditions relate to the length relationship between crankshaft stroke and connecting rod length. More specifically, "long rod" engines tend to have a narrower span of rpm between peak torque and horsepower than engine of "short rod" configuration.

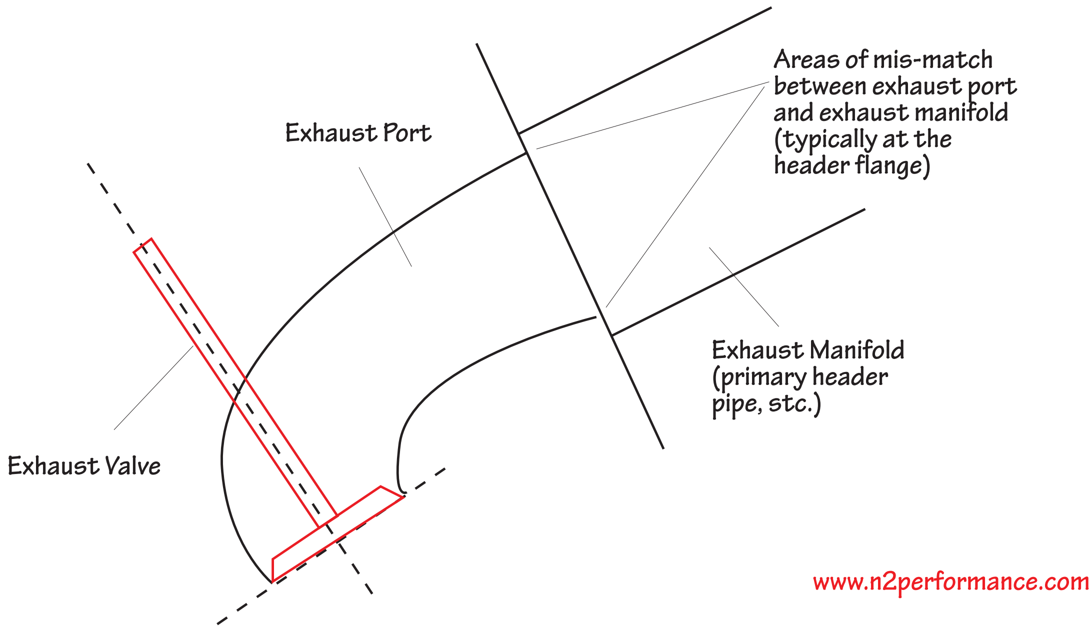
In the selection of an exhaust system, headers in particular, this "rod-to-stroke" ratio should be included in the decision-making process, primarily because it points to a range of rpm largely influenced by this ratio and where the remainder of the engine package should be directed for best power. This can become a bit clouded. Let's consider an example.

Suppose we have an engine in which the rod-to-stroke ratio dictates the engine will operate in a high and narrow span of rpm. In the case of an exhaust system, we want to select (or build) a system that addresses torque output primarily within this span. The need for a "broad band" header that enhances torque over a wider range or engine speed isn't necessary here. Instead, we can eliminate the importance of a collector, trend toward short primary pipes and select a pipe size that encourages a torque peak on the low side of this narrow span of rpm. Again, it's critical to consider the packaged or "parts bundled" approach. As these lectures evolve, more and more references will be made to the importance of parts integration, once engine application objectives are determined.

Exhaust porting

Same deal here, compared to valve timing and piston motion. Be critical about the rpm range in which the engine will be run. If you're using a set of cylinder heads for which marked improvement to exhaust port flow is provided, take this into consideration when deciding upon header dimensions. Again, you'll need to choose an exhaust system (primarily headers) that favors improved engine breathing at the higher rpm. Engines that will be primarily operated in the low- and mid-rpm range respond well to un-ported exhaust passages, exhaust valve

Illustration of a Common Reversion Containment Method



Note: Some measure of reversion containment can be accomplished by a physical mis-match between exhaust port and exhaust manifold (typically a header primary pipe) by allowing pipe I.d. to exceed port I.d. This mis-match is often accomplished at the exhaust header flange-to-head interface.

timing that's longer than the intake period (dual-pattern) and header primary pipe size that achieves the desired flow rates in a torque range most often used. (Header sizing vs. piston displacement vs. rpm is coming up in later paragraphs.)

Combustion efficiency and backpressure

The relationship between backpressure and combustion efficiency was pointed out earlier. Looking into the issue further we find that the issue is not just the contamination of fresh air/fuel charges but also the effect this dilution has on mixture ratios within the combustion space.

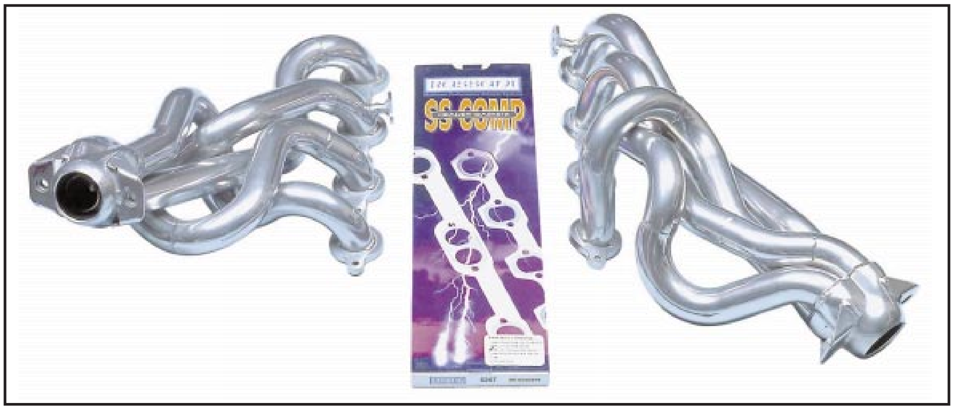
What happens is that residual exhaust gas occupies space in the cylinder. Everywhere it exists, fresh mixture cannot. Aside from inherent variations in air/fuel ratio that are normally found in the combustion space, prior to and during the burn, residual exhaust adds another component that varies the blending of air, fuel and diluting exhaust gas. Aside from not participating in the combustion process, residual exhaust gas tends to reduce combustion flame temperature…further damaging combustion efficiency. As this temperature is decreased, additional opportunity for the flame to be quenched arises.

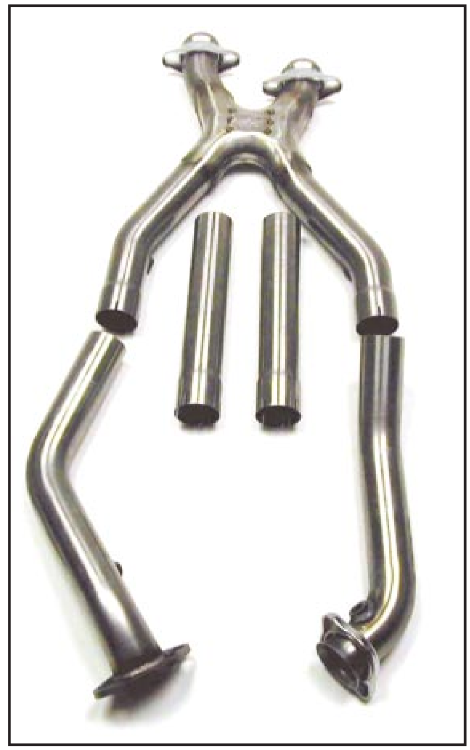
The point is that the effects of backpressure are more influential than just reducing an engine's ability to move exhaust gas. A restrictive system can exist at low rpm just as well as high. In either case, the results are the same. So once again, it is critical to determine the rpm range in which optimum power will be sought, tailoring the exhaust system to (1) provide torque benefits in this range and (2) limit the amount of backpressure it causes.

You may not feel that the system you are currently using (or plan to use) is sufficiently restrictive to cause concern. However, if you find that an inordinate amount of fuel is required to make best power or more spark timing is required than you believe necessary, both conditions point to contamination in the combustion space.

Header sizing, piston displacement & rpm

Believe it or not, these issues are inexorably linked. If you plan to optimize an engine's exhaust (header) system, there is a simplified, mathematical approach you can take to sort out the details of this relationship. Over many years of matching header sets to engine packages, we've found this method to be one of the best "short cuts" available. But before we lay out the technique, it's important to understand why these three areas are related to each other.





Street Header (top) - In this Bassani truck header design, particular effort is made to produce primary pipes of equal (or near equal) length. Primary torque gains come from specific primary pipe lengths, rather than any dependency upon header collector volume. Short collectors allow for beneficial increases in primary pipe length.

X-Pipe™ Brand Crossover System (right)
Bassani Xhaust offers this version of crossover system, providing additional torque boosts below the engine's torque peak. Particular benefits are derived using this system in conjunction with applications for towing, hauling or general low-and mid-rpm performance requirements. Also works well for street performance engines (especially automatic transmission powertrains) where mid-rpm torque and driveability (including drag racing "bracket" cars) is desired. **Photo courtesy of Bassani Xhaust**

It has been conclusively demonstrated that even though exhaust flow is unsteady state flow, a "mean flow velocity" exists in header primary pipes at any point in the rpm range. At peak torque, there is a m.f.v. observed to be in the 240-260 ft./sec. range. Based on this, we can take another perspective and say that if we want to influence an engine's torque peak rpm point, selectively, then we can size primary pipes to produce this flow velocity at the desired rpm. This, then, becomes a design tool for either sizing or evaluating header pipe diameters.

Since we know that flow velocity in a passage is cross-section area sensitive, we simply determine the volume of air to be passed at the rpm where 240-260 ft./sec. flow velocity is targeted and size the pipe accordingly. Here's how that can work…and this is the equation.

Peak torque rpm =
(Primary pipe area x 88200) /
Displacement of one cylinder.

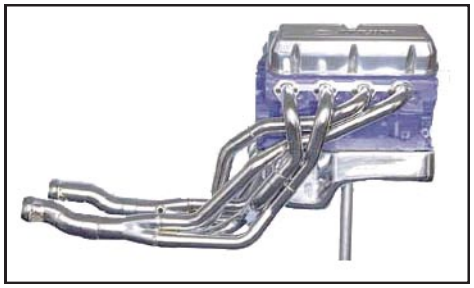
Let's plug in some numbers. If we have a header with a primary pipe cross-section area of 2.0 sq.in. and an engine with 43.75 cu.in. per cylinder, the equation works out to a peak torque rpm point at 4032 rpm. Recall we said earlier that primary pipe length does not determine the rpm at which a torque peak or boost (for the exhaust system) will occur. In this equation, nothing is included about pipe length.

Now, suppose we take some different views of this little mathematical model. If we want to establish an exhaust system (headers) torque peak at a pre-determined rpm (and will either build or select header pipe size accordingly), some algebraic transpositions will allow the equation to be solved for primary pipe area.

(Note: When making these computations, be sure to compensate for pipe wall thickness, because it is cross-section of the inside of the pipe that you are seeking to calculate and use in the equation. For example, a pipe of 2.0 inches o.d. may have a wall thickness of 0.040-inch. Taking this into account, the actual diameter with which the cross-section area is computed becomes 1.92 inches.)

If we already have a set of headers (or are anticipating their purchase) and are curious about where it will provide an exhaust system torque boost, the equation can be re-arranged to solve for rpm…at which the headers in hand will produce their torque boost.

Of course, as piston displacement is changed, so will the performance characteristics of a given set of headers. A general example of this is that a set of headers producing a torque boost at 4000 rpm on a 350 cu.in. engine will reach this peak sooner on an engine of 400 cu.in. Simple manipulation of the equation provided will show why this is true.



Bassani "Stepped-tube" Design Header - Introduced for 5.0L Ford Mustangs, this design is now featured in a variety of Bassani products, including applications for light-and medium-duty trucks engaged in towing, hauling or similar situations where low-and mid-rpm torque gains are of benefit. Essentially, two "torque peaks" are produced with this concept; one for off-idle accelerations and the other placed at engine speeds associated with conventional up-shifting during wide-open throttle conditions.

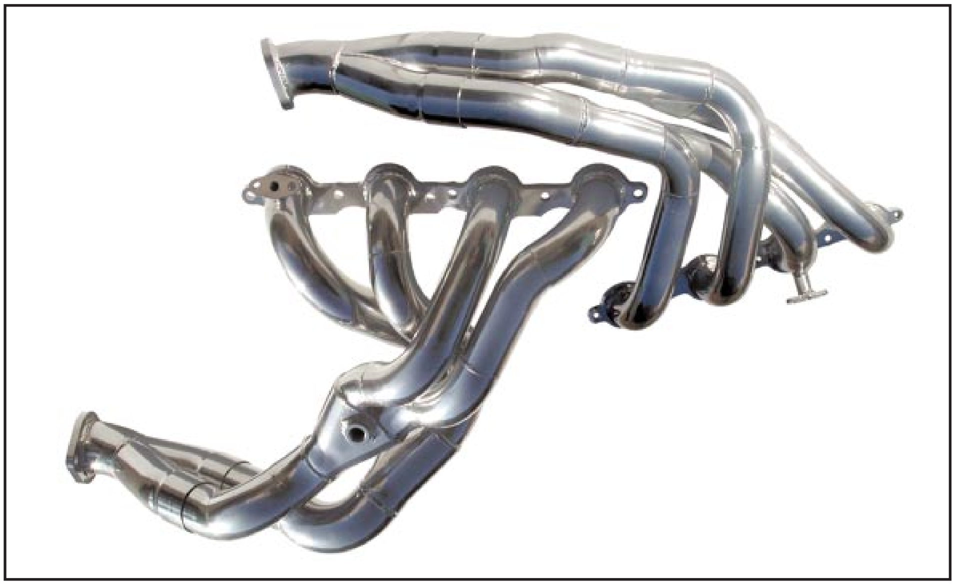
Photo courtesy of Bassani Xhaust

"Stepped" headers

While this method of broadening an engine's torque curve has been used on racing engines for many years, Bassani Xhaust was one of the first to introduce the concept to high performance street headers. Called the "Stepped-tube" design, Bassani found that by proper sizing of primary pipes and location of a "step" that increases pipe diameter, selective torque boosts could be applied to street-driven, high performance engines.

The notion of two-sized primary pipes is pretty direct. Since pipe diameter fixes the rpm at which a torque boost is provided, the use of two different primary pipe cross-section areas (in the same header set) theoretically produces two peak rpm points. In reality, the effect is a broadening of the torque curve to include two pre-selected rpm at which a torque increase is desired.

For example, it is helpful for a torque curve to have one boost in the



Bassani's "421" Series Header - A precision-engineered design "Tri-Y" header incorporates several power-producing features. Among them are stepped primary pipes (providing a broader and flatter torque curve), a crossover pipe for additional low rpm torque, and reversion damping chambers at the junction between the two sizes of primary pipes. The result is a broadband, torque-producing header for high-winding import engines required to operate over an extended range of rpm. **Photo courtesy of Bassani Xhaust**

area of initial vehicle acceleration and a second in the span of rpm to which the engine falls during up-shifts. As it turns out, this approach to header design has proven of benefit to light- and medium-duty trucks engaged in hauling or towing activities, according to the success Bassani has enjoyed with this approach to header design.

Equal vs. un-equal header pipe length...and some concluding thoughts on this month's lecture...

While it has required some precision test and data acquisition techniques, the following information seems to support the theory of primary pipe length and its effect on torque curve development.

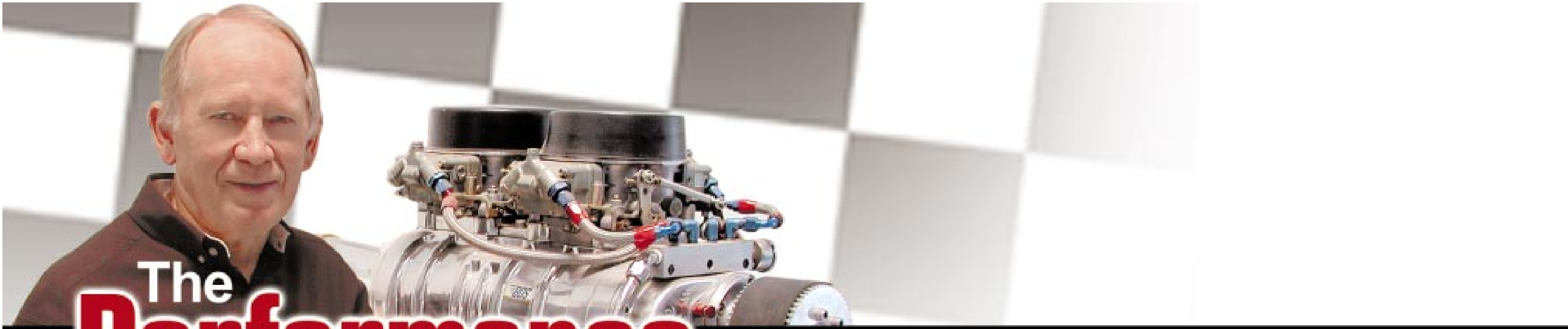
Earlier, it was mentioned that changes in pipe length tend to affect the "rocking" of a torque curve about the rpm point (peak) determined by pipe cross-section area. Taken a step further, consider that each pipe in a set of headers is capable of producing a "torque curve for each cylinder to which it is connected." Given that analogy, a set of headers with equal length primary pipes will produce a "set" of torque curves (combining all cylinders), each with its respective torque peak at one rpm and shaped equally, one curve to the other.

If this same set of headers is constructed with primary pipes of unequal length, we can reckon there will be multiple torque curves, all peaking at the same rpm but rotated or counter-rotated about this rpm. In theory, this would tend to "soften" or broaden the torque curve, not reducing the area under the net curve (total work available) but re-shaping the curve in the process. Interestingly, available test data bears out this concept.

Perhaps a clearer picture can be obtained if you consider that a multi-cylinder engine is a collection of single-cylinder engines. This approach makes increasing sense as each cylinder is fitted with its own intake and exhaust path.

Furthermore, it's possible (and documented) that each of these cylinders could be provided its own set of intake/exhaust valve timing patterns and spark timing curve. And if you are getting the impression that this "tuning one cylinder at a time" notion is borderline reality, we share with you that the technology of Engine Cycle Analysis (to be discussed in a future n2performance.com lecture) has opened the door to the development of just such engine packages!

Hard core results from the ability to and practice of configuring race engines to optimize single cylinder power output has been putting rubber on NHRA and NASCAR tracks for more than two years. And that's just addressing the teams who've not prevented this type of information from leaking past security measures. In time, more of this will be discussed on the n2performance.com site. It will be worthwhile to continue your visits.



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"Performance Professor" Interview - with industry notables

Jeff Smith: Editor - Chevy High Performance Magazine

Jeff Smith is clearly the most hands-on automotive enthusiast, print media Editor I know. His years of management positions at EMAP USA (formerly Petersen Publishing Company) include several staff positions at Car Craft Magazine, HOT ROD Magazine (Editor) and his present position as Editor of Chevy High Performance. Along his career path, Jeff has carved out countless carefully-planned engine-building projects, each directed to the core of understanding why parts function as they do…with editorial clarity unequaled among his peers.

In particular, his experience with headers is extensive. On more than one occasion, he has compiled an orderly and painstakingly accurate series of tests that address the matching of exhaust system "theory" to "results." The following discussion, framed in typical Jeff Smith candor, is a sharing of this thoughts and experiences on the subject of high performance (and racing) headers. The information is invaluable and, not coincidentally, closely parallels material you find in this month's Performance Professor Lecture. Here's Jeff.

To properly select exhaust headers for a given engine application, it's important to know that theory and results are related. In your experience, how do you see this relationship?

"Over time, I have had the opportunity to see first-hand how the various theories of exhaust tuning work. In fact, in the January '99 issue of CHP, we configured a series of engine dyno tests that involved ten sets of headers, each separate in design from the other. The purpose of the tests was to first show how exhaust tuning theories manifest themselves in real-world testing and then to set guidelines that enable enthusiasts to make sensible header selections. Results from those tests were so significant that I often refer to them to underscore the value of relating theory to results.

"In particular, we found that primary pipe diameter and length are critical to where in the rpm range torque is produced. As I said in the story, 'Primary pipe diameter closely dictates the speed of the exhaust gas exiting the engine. This exhaust gas speed directly affects the peak torque rpm point.' What this means is the larger the pipe diameter (all else being equal), the slower the exhaust gas speed will be. I also noted, 'This tends to push the peak torque to a higher rpm.' Of course, as you would expect, a smaller pipe diameter tends to lower peak torque rpm. Changing pipe length tends to rotate or shift the torque curve about this peak rpm point. For example, increasing length adds torque below the peak and removes it from above. Shortening the pipes does the opposite."

"Judging from what you can buy among today's header designs, it appears the aftermarket industry still hasn't quite picked up on this relationship. For example, nobody makes a header for small-block Chevy's with an inch-and-a-half pipe o.d. I realize Hedman makes what they call a "Tork-Step" design that incorporates two sizes of primary pipe diameter, intended to broaden or 'fatten' the torque curve by tending the torque curve to have two 'peaks.' But in general, the industry hasn't seemed to realize the value of small diameter, long primary tubes."

If there are misconceptions among performance enthusiasts about certain features of headers, what do you believe them to be? Stated another way, what's the most common mistake you think is made in the selection of headers?

"Pretty simple. Bigger is not always better. Neither are large diameter pipes that are short.

What the enthusiast needs to remember is this. To properly evacuate the cylinders, a certain level of exhaust flow velocity is required. Of the factors that affect this, piston displacement and rpm need to be considered. For example, a small engine running at relatively low rpm cannot benefit from headers that don't encourage good exhaust flow in this range of engine speed, especially since not much air is being displaced. But as either engine size or rpm are increased (or both), exhaust flow rate increases and larger pipes can be of help.

"Also, it's important to not attribute specific power gains just to a set of headers. Headers, even the correct ones, installed on an engine that's making 350 horsepower don't tend to show the gains on one producing 450. If cylinder pressure (horsepower) is low, the benefits to be derived from improving exhaust gas flow simply won't be as great if the pressure levels are higher.

"And finally, all headers are not created equal. An example of this is how some of the 'shorty' designs compare to stock, cast-iron exhaust manifolds, especially at low- and mid-rpm I've seen cases where the cast-iron pieces were better, probably because of the poor tuning characteristics of the short pipes."

As the Detroit community has re-entered the "performance business" during recent years, how do you compare stock exhaust systems to those available in the performance parts aftermarket?

"There's no doubt the OEMs have made it more difficult for header manufacturers to show gains. But it's the 'package' concept, once again. Late model engines represent improved parts integration, resulting in exhaust systems that are tuned more to the proper power range. In the past, header manufacturers had little difficult producing systems that delivered 25-30 horsepower, especially in the higher rpm ranges. Today, that's changed. Incremental gains more on the order of 10-15 horsepower are the norm among aftermarket header manufacturers, particularly with respect to engines required to operate through exhaust systems that include catalytic converters. The OEMs have clearly raised the bar of performance to the aftermarket."

How do you rate exhaust system modifications to other "bolt-on" approaches to improving engine performance?

"Whenever we've planned a step-by-step, parts bolt-on story, we always start with exhaust system modifications. In my experience, the biggest gains (particularly with late-model engines) come from exhaust modifications. I remember when I was in college and driving a two-barrel, 283 small-block Chevelle, the muffler gave out. So I decided to install a dual system, just because I thought I'd like the sound. I was shocked because of the gain this produced, simply by the reduction of backpressure. I can't even remember what it sounded like. It was just like I'd added another 100 cubic inches!"

As a magazine editor, what do you strive to do when configuring an engine for test purposes, and how do you approach sharing the results framed to optimize benefits to the readership?

"I always try to use an engine package that really relates to the reader. Generally, something around 400 horsepower, without any frills that will tax the engine (increase its level of sensitivity to modifications) but not put the combination into the realm of exotic. It may be nice to read about mega-horsepower, double-everything, but this isn't what our readers work on or drive. So why take them into never-never land when they aren't going to go there or can afford the costs to do so, even if they wanted. We like to show down-to-earth performance differentials based on the types of modifications that readers are likely to make. If we can help avoid costly mistakes, even make them for the readers so that they don't, then I think we've done a proper job."

From your perspective, what do you foresee in the future of high performance exhaust systems?

"I will say that 'exhaust note' is the coming issue and that designs will be based on tuning for specific applications. I also know that there's work going on that addresses specific sound frequencies and their control by the exhaust system, mufflers in particular. There are certain frequencies that are pleasant, others that are injurious and still others that even affect driver mood. Believe me, it's true. In fact, I think you'll see more and more of this type research evolve, particularly since the OEM's have already carved into the performance aftermarket header industry. Look at the import performance market. You don't see any significant power gains coming from the modification of these systems. Sound, yes. But not power. Yet, there'll likely be an opportunity, as I said, for application and engine-specific modifications to exhaust systems for a long time to come."