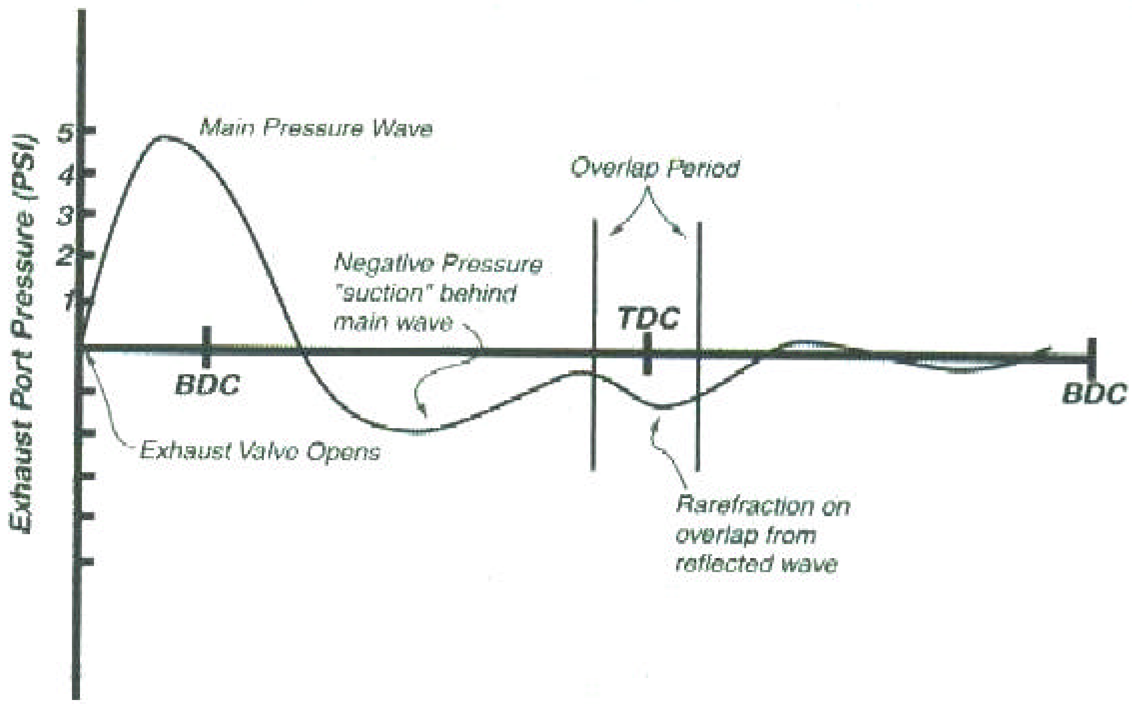
Backpressure: Friend or Foe?

Backpressure can influence in 2 places. Just at the start of when the exhaust valve opens and at cam overlap.

Figure 1. Pressure measurements at the exhaust valve during the start of the exhaust stroke at BDC to cam overlap at the end of the exhaust stroke/beginning of the intake stroke at TDC.

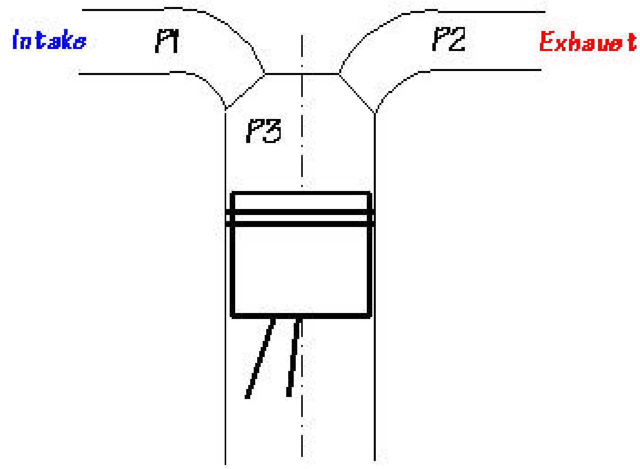


Notice the positive (backpressure) spike at the far left as the exhaust valve just opens at BDC. The exhaust gases must now push against this POSITIVE (back)pressure before it can leave the combustion chamber. The pressure tracing is upwards and positive. Energy must be used up in order to overcome the initial positive (back) pressure in the exhaust system before the exhaust gas is pushed out of the combustion chamber.

After we are able to overcome the positive backpressure, you see that the exhaust gas begins to travel faster and creates a NEGATIVE pressure. The pressure tracing in the diagram is downwards or has a negative value. The more negative a pressure becomes means that you are creating more suction or a vacuum in the system. The system is literally sucking or pulling out exhaust gas from the combustion chamber or cylinder. This sucking or "SCAVENGING" effect not only helps remove more exhaust gas from the cylinder. It also helps suck in more intake air & fuel mix at cam overlap. The faster the exhaust gas travels the more vacuum it creates. We want to get as much as negative pressure created before cam overlap.

Figure 2. Pressure at the intake port, in the combustion chamber, and in the exhaust port at cam overlap and afterwards. Everything is interconnected. The pressure in one section affects the pressure inside another section.

Pressure Relationships Before, During, and After Valve Overlap



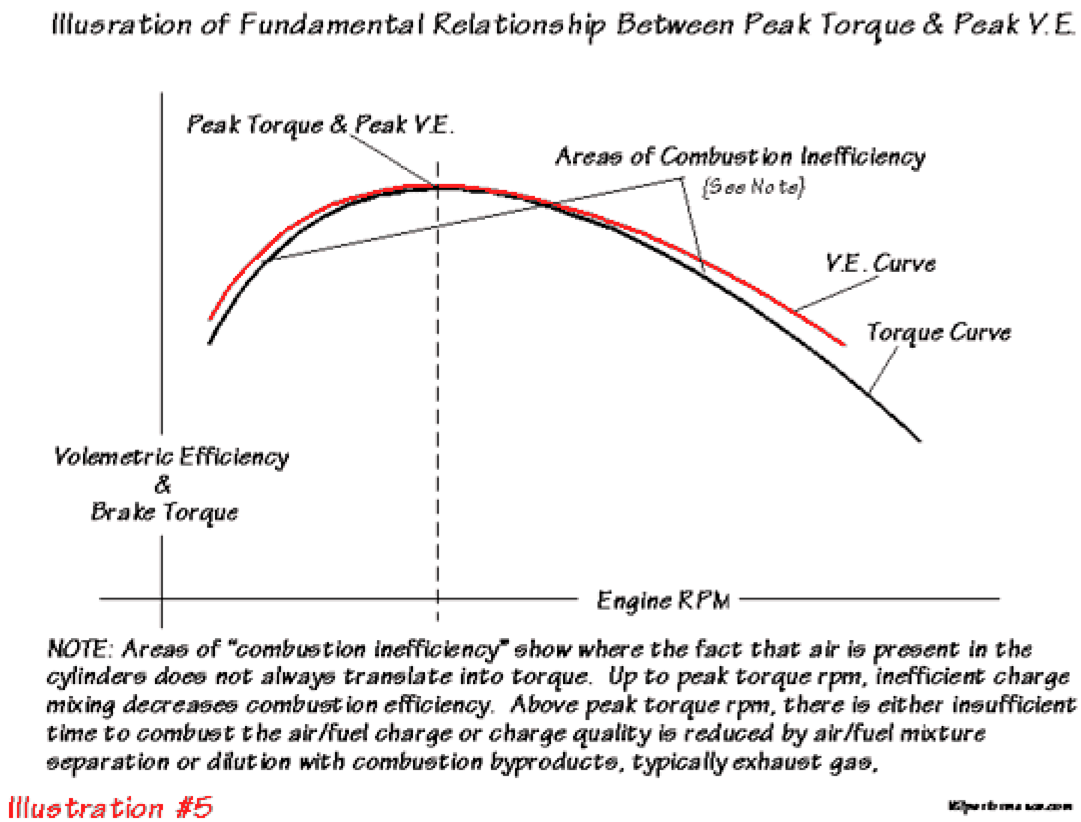
Immediately prior to overlap - P3 > P2 since upward piston movement is displacing exhaust gas from cylinder into the remaining exhaust system. Depending upon system back pressure, the value of P3 and rpm, P3 may remain higher than P1 at the time of intake valve opening.
Valve overlap period begins - P3 > P2 > P1. For a brief period, this condition causes exhaust gas to flow back into the intake system. At the point P1 > P3, the cylinder will begin to fill. However, if before this occurs and the exhaust valve is not yet closed, P1 > P3 and P2 can cause fresh air/fuel mixtures to pass through the cylinder and into the exhaust system, unburned. The is the referenced "over-scavenging" condition.
Valve overlap period ends - At this point, the exhaust valve closes, P1 remains > P3 and the cylinder continues filling until the intake cycle is completed.

At cam overlap, if you look at Figure 1., there is a reflected pressure wave traveling backwards towards the engine. This reflected wave or "REVERSION" is what contaminates the intake charge at cam overlap and reduces or dilutes the oxygen content coming into the cylinder. Less oxygen going in means less power. Notice the pressure at the exhaust valve is still negative but less negative than before. This reflected exhaust wave or pulse is the second backpressure we experience and again reduces exhaust flow speed or energy because the exhaust pulse must now push against this pressure to move forward. A loss in flow speed means less negative pressure, or vacuum, or suck.

The bottom line to remember is that more backpressure means adding it at 2 times and that it slows down flow speed. Slowing down flow speed reduces scavenging and efficient removal of as much exhaust gas out of the cylinder before we start filling the cylinder back up again with fresh air (oxygen) and fuel for the next engine cycle (next set of intake, compression, combustion, and exhaust strokes).

If you think that leaving some exhaust gas behind in the cylinder before the next intake stroke is not important, look again at Figure 5 below. This is, once again, Jim McFarland's classic graph comparing the volumetric efficiency curve versus the torque curve. As I stated in the cylinder head article where you first saw this, notice that these 2 curves have the same shape but are not exactly identical or overlaid on top of each other. You would think that once you have maxed out on the engine's breathing ability (volumetric efficiency), the torque or power curve and volumetric efficiency would be identical. They are not. Why? Flow quality on the intake side and inefficient removal of exhaust gases out of
Figure 5. Volumetric Efficiency Curve Compared to Torque Curve. The VE Curve shows how much power you would

make if you maxed out and improved engine breathing (flow volume), flow quality, and exhaust removal. The torque curve shows you the power if you don't pay attention to flow quality (in the low to mid rpms) and cylinder exhaust gas removal (in the upper rpms).



Comments from Some Experts on Exhaust Backpressure:

1. Larry Widmer of Endyn on Exhaust Backpressure:

quote:

"***from 21st Century Performance Book***

Few tests have been done that clearly show the effect of changing back pressure. Most muffler and exhaust comparison tests change more than one parameter simultaneously, making the identification of exhaust backpressure as a culprit difficult.

However, Wollongong (Australia) mechanic Kevin Davis has done extensive testing of varying backpressure on a number of performance engines.

These range from turbocharged Subaru Legacy RS flat fours to full-house traditional pushrod V8s. In not one case has he found any improvement in any engine performance parameter with increased exhaust backpressure.

The tests came about because Kevin has developed a patented
variable-flow exhaust that uses a butterfly within the exhaust pipe. He initially expected to use the system to cause some backpressure at low loads 'to help torque.'

However, he soon changed his mind when any increase in back pressure proved to decrease torque on a properly tuned engine. What increasing the backpressure does do is dramatically quiet the exhaust.

One of the engine dyno tests carried out by Kevin was on a modified 351-4V Cleveland V8. Following the extractors he fitted a huge exhaust that gave a measured zero backpressure. Torque peaked at 423 ft-lbs at 4700 rpm, with power a rousing 441 hp at 6300 rpm. He then dialed-in 1.5-psi (10.4 kpa) backpressure.

As you'll see later, very few exhausts are capable of delivering such a low backpressure on a road car. **Even with this small amount of backpressure, peak torque dropped by 4 per cent and peak power by 5 per cent. He then changed the exhaust to give 2.5-psi backpressure. Torque and power decreased again, both dropping by 7 per cent over having zero backpressure.** These results were achieved on a large engine with a large overlap cam - one of the types some people suggest is 'supposed' to like backpressure.

If, in fact, power does increase with increased exhaust back pressure, it is most likely the air/fuel ratio and/or ignition timing that are no longer optimal for the altered state of engine tune."

Larry Widmer comments on the above textbook quote:

At less than WOT and peak power rpm, the diameter of the tubing should change in ID. Just as with intake ports (unless we're just running off port volume), cross sectional area should be only sufficient to supply the flow rate necessary to feed the engine.

High velocities, that don't incur pumping losses are the rule.

The exhaust system is much the same. Just changing backpressure is a bogus way of trying to create the "ideal" pressure in the system. The exhaust system should work like a correctly conceived header. It should extract the exhaust from the header, to minimize pumping pressures.

The only way to create a system that will serve as an extractor is to properly size the tubing to allow the flow velocity to create a sort of "vacuum" behind it.

Just as with headers, creating a system that will provide the best of all worlds at all throttle positions and rpm ranges is impossible. It's all going to be a trade-off. You can tune for the throttle positions and rpm ranges where you desire the greatest performance, but you'll sacrifice performance at the other end of the rpm range.

Building a system to divert the flow into a smaller system can help bolster lower rpm power, just as with today dual runner intake manifolds, but you'll never find a dual runner intake on any engine that's targeting the greatest performance potential possible. I should also add that such systems are inefficient from a standpoint of weight and surface area.

For mid-performance applications, these type systems will be as popular as their costs will allow.

In our quest for "more", we seldom work to achieve mid-level (mid rpm range) performance, so just as the gentleman who wrote the book in the post from above, we prefer to tune with **the least amount of backpressure possible**. We do have to observe rules and regulations (noise levels and EPA regulated emissions) and the systems must fit the vehicle in question without dragging the ground, so there will always be compromises.

I suppose that I should mention that cost is another consideration. If it wasn't, a lot of our street systems would have greater area and they wouldn't necessarily be circular in configuration either.

In the stock ITR, backpressure becomes a power "liability" by the time the engine's making 210 flywheel HP. Relative to wheel HP, if you're making more than about 11 HP more than "stock", the system's costing you....and yes, **detonation can be caused by excessive backpressure.**

The other problem you face with excessive backpressure is one of reversion. The higher the backpressure, the more inert exhaust components re-enter the cylinder. A few of these bad-guys can really steal big hunks of power in a hurry. **If you don't believe me, just run a pipe from your exhaust tip up near the air cleaner on your next trip to the dyno. A little sniff of the exhaust will absolutely kill your power.**

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2. Calculations and Comments by Dave Stadulis of SMSP Exhausts Relating Flywheel HP to Exhaust Cross-Sectional Area (Diameter):

quote:

Here are the numbers for 16g tubing:

OD (in.)....ID (in.)...Area....%Increase......HP.......HP/in^2

2.25........2.120.......3.53.....0%..............200.......56.66

2.50........2.370.......4.41.....25%.............275.......62.34

2.75........2.620.......5.39.....22%.............318.......59.00

3.00........2.870.......6.47.....20%.............400.......61.83

OD is exhaust outer diameter, ID is inner diameter, Area is tube cross-sectional area, % Increase is increase from the prior OD, HP is **Flywheel** hp, and HP/in^2 is hp per square inch cross-sectional area.

For the 2.75 in. tube, I assumed 59 HP per square inch of flow area, I used Larry's numbers for the others....you are talking **HP at the crank** :

2-1/4" for up to 200HP @ the crank, 2-1/2" for 275HP, 2-3/4 for 320HP...

or **60HP (at the crank) per square inch of (cross-sectional) flow area**.

This **60HP/in^2** is to get you in the general vicinity. It also is based on the inside diameter of the tubing not the OD (i.e. 2" in your example). The ID for 2' 16g tubing is 1.87" and this will yield a limit of 165 crank HP. 2-1/4" 16g (212 HP), 2-1/2" (265 HP). Now you can get different sized tubing such as 2-1/8" and 2-3/8" to fine-tune a vehicle but you can't get cats and mufflers in those sizes so you should go up a size when building an exhaust in those cases.

Question: Do you have an opinion concerning the best choice for harnessing exhaust pressure waves when a catalytic converter is present at the manifold? ... I'm just curious at a theoretical level. : Here are the possible choices:

1. Gut the manifold mounted converter, so it acts like a pressure wave plenum, and replace the smaller converter downstream with a larger converter (coating the exhaust to encourage light off). As with the intake manifold, there should be some pressure wave tuning occurring somewhere in the rpm band.

2. Use a manifold/header, which does not have a converter mounted to it, and install a pressure wave plenum immediately in front of a larger manifold type converter downstream (once again coating the exhaust to encourage light off). Same benefit as above, but allows some tuning flexibility since the plenum location can vary.

3. Ignore exhaust pressure wave tuning; it's not a significant issue with a stock valve train.

SMSP replies:

I believe you can affect the overall performance of your system by the placement of the cat, since you have a volume change when the exhaust gases enter the cat. But then temperature does become an issue for the emissions performance of the cat.

Same goes for running an open header versus a header with a short tuned tail pipe. Tail pipe length is very important, it just takes a lot of testing to determine what is right. I know of a guy who played with different length tail pipes and picked up 5-6 HP on a 190+ WHP engine.

To take full advantage of the system you have test and tune, many many times. I believe a tuned length tailpipe will get you the most power, versus running the header open (nothing after the collector)

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3. John Grudinsky at HyTech Exhausts comments on the usefulness of backpressure:

quote:

I have seen where a little backpressure, helped out the very low end of a 4-cycle engine because it had a lot of valve timing and it stopped some of the scavenging of the cylinder and (therefore) helped the power. But as the motor revved up, the gains were diminished and it lost power on top (in the upper rpms). There has been exhaust systems designed to actually reverse feed the cylinder through the exhaust port, before the valve closes on overlap. It actually has worked, but it didn't seem to work over a large rpm band but in a short (rpm) one, it worked quite well.
