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[Porting School #8 Optimal Port area's](#) **Porting School #8 Optimal Port area's**

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[DavidVizard-GFN](#) **OFF**
 Pit Crew

Join Date: Apr 2007
 Posts: 840

Porting School #8 Optimal Port area's

#8 Determining Optimal Port Area's

In part #7 we looked at the effect of differing port area's on the output of a 383 small block Chevy. This test may have made the determination of port area appear relatively simple – but the reality is far from being so.

By

David Vizard

I'm at the race track and some racer/engine builder recognizes me (it does happen from time to time!) and walks over and asks why I think their motor is not performing quite as well as they think it should. My first question is usually "got a decent set of ported heads on it" The scariest answer I get is along the lines of 'yes, they are re-worked, we have opened up the ports on the heads". That tells me right there I am talking to someone who probably has little knowledge of heads. However I caution myself here with the thought that where would they find such info so as to be an expert in this field? There's not much out there and that is just one of the reasons we have GFN's Porting School.

In Porting School #7 (PS#7) it was demonstrated how port area (we dealt with it in terms of volume dimensions) affected the power output of a 383 small block Chevy. Using a pushrod two valve per cylinder engine as a guinea pig may have left our four valve fanatics somewhat less than satisfied in terms of what they could potentially learn. Here I intend to look at ports from a much more theoretical aspect so that what is put forward covers all types of poppet valve four stroke engines.

So far we have learned that air has far more mass than most people suppose. From this and the dyno results shown in PS#7 we can see that getting the port optimally sized is worth additional output over the entire rpm range. Not only that it can be instrumental in expanding the rpm range. The end result is that the extra torque produced has very much the same effect as having a bigger engine without any of the down side of such. At this point you should have a clear understanding that getting the port area right for the application is of great importance.

So is all this port sizing going to be just a case of simple proportions? Not a chance - but we need to start somewhere and before doing so, I need to make it clear we have to deal with two distinctly differing situations when determining port sizing. The first is a no-holds-barred race engine – the second is an engine that has a distinct rpm range within which it must be optimized. Street engines normally fall into this category. Also in this second group are race engines that call for a valve lift limit at, or below about 0.25 of the diameter of the intake valve. Why this is so will unfold later. For now let's get going on the fundamentals – first port of call here will be valve sizes.

Optimum Valve Sizes.

Like most aspects of head design there is more to this than meets the eye. But anything more than what we need to know to quantify port size/area I will deal with in a feature if it's own. For now I just need to establish a few pertinent parameters.

The first and most important of factor is that if we are seeking to make the most torque from a given compression ratio over a specified rpm band then the valve sizes needed are the largest that can be installed without incurring a mechanical problem.

I make the afore mentioned point because there is a misconception that if torque at a lower engine speed is the goal then this can be had by using smaller valves. I recently was talking to a seriously good head designer who had the job of developing a cylinder head in terms of flow where the customer had specified he wanted valves smaller than usually used so as to make more torque. My seriously good head designer did not have the heart to tell this customer that what he needed to do the job was smaller ports not smaller valves. Still on the same subject the Avenger engine I did for Chrysler that had a power band from 400 to 8000 rpm had valves that almost filled the cylinder. This car drove like it was powered by an electric motor rather than a gas burner.

OK so rule # 1 here is that if you are seeking to maximize output over a specified rpm range the biggest valves possible are where you should start. From this point on it's a question of port area and cam selection.

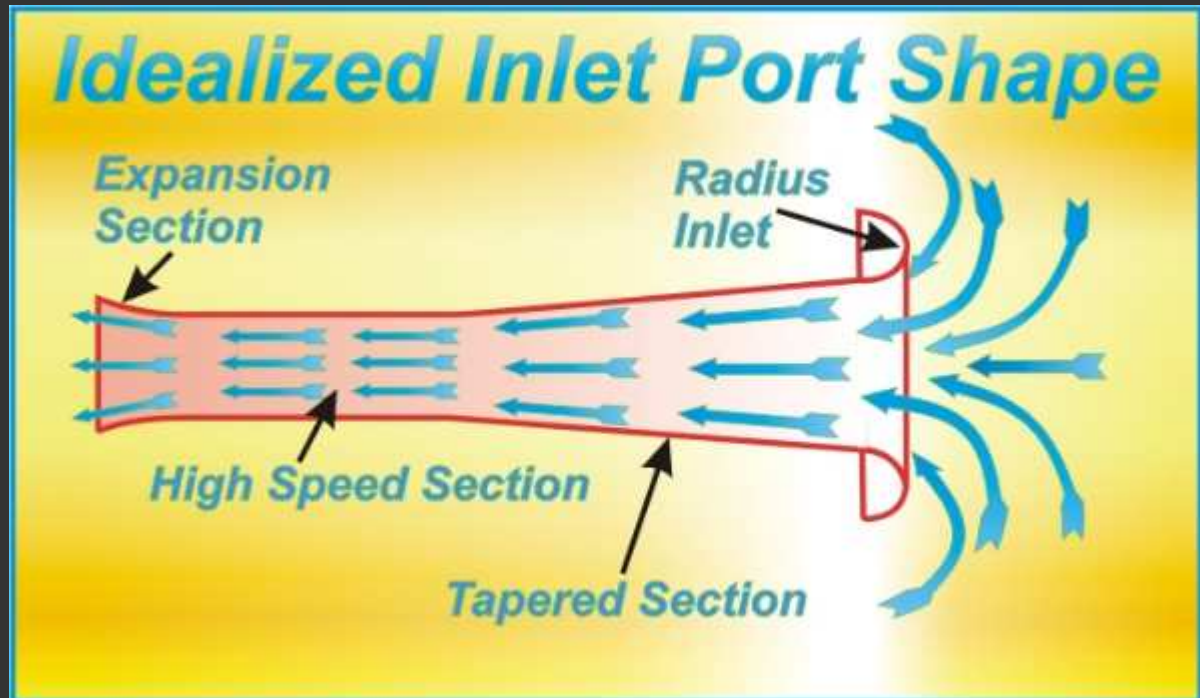
The only time small rather than maximum size valves fall into consideration is for a production line engine that has to make a power figure that the marketing department consider to be what is needed to fit customer requirements in that market section. If the market calls for 100 hp and 120 lb's-ft then, after the engine designers have achieved this, they go on to look at other aspects. We are not in that business – we are looking for the best bang-for-the-buck for the cubes we are dealing with. That being the case the biggest valve possible are ultimately the best.

For a race engine the choice of valve sizes could not be simpler. Use the biggest that will mechanically

fit!

Idealized Ports.

Probably the best place to start is to consider an idealized port that is optimally shaped for best results when the valve is at 0.25D or more in lift. This being the case we can look at an idealized port as a straight tube with the valve removed from the picture. To pass as much air into the engine during the time of the highest mass flow per unit time we will have an idealized port along the lines shown below.



If we lift the valve beyond the sphere of influence of the seat, then straighten out the port and proportioned it for the best results, we would end up with a shape along the lines shown here. To get the air to flow smoothly into the induction tract a generous radius is required at the open end. Too large a radius though will reduce the effectiveness of the length tuning. A radius of about 3/8th to 1/2 inch appears to work well. From the entry point the port needs to taper down to a parallel section at an angle between 2 to 6 degrees inclusive. The next part of the port is the fastest section and is sized for one of two purposes. If it is an engine that has to operate over a given speed range that is less than an all out race engine then the port size is to suit the operation range concerned. If the engine is an all-out race engine then the port is sized to feed the valve the most amount of air consistent with maintaining good velocity.

Let's go step by step through the port diameters here and consider what we might be shooting for. The first step is to understand that the valve and seat that ultimately will fill the hole at the cylinder end of the port is always short of 100% efficient. This means that as far as flow is concerned the valve and seat looks just like a hole somewhat smaller than the valve itself. If we have a good idea what sort of efficiency the valve and seat have and what the equivalent hole size would be we are starting to get an idea what the size of the biggest useful port might be for the parallel section of the port. With typical flow efficiencies past the valve at lifts above 0.25D we find that the parallel section ceases to be a significant flow restriction when it is about 75-80% of the valve area. This means the port is between 86.5 and 89.5% of the valve diameter.

At this point it might look like we have nailed this port size requirement right here. At last a definitive port area for a given valve area. Unfortunately this is not the case. All the forging still makes a few assumptions. The first is that we are dealing with a valve that is between 1.5 to about 2.5 inches in diameter and that such valves have a 0.06 inch wide seat blending into a radius of 6.3% of the valves diameter. On a typical 2.02 inch diameter Chevy intake valve this would give a throat diameter at the end of the radius equal to 92.5% of the valve diameter. The problem we have is that valve seat proportions for best flow are not fixed. A small valve requires a slightly larger under seat radius for best results than does a very big valve. All we have going for us here is that within the bounds of the valve sizes I have just dealt with the changes are small.

The other aspect we have to deal with is that ports in real life are far from straight! The angle the port approaches the valve also has a distinct effect on what the optimal area for best output will be.

Pre-valve Flair

With the typical throat diameter of a theoretically optimum port being about 92.5% of the valve we find that the port is going to get larger in area as it approaches the valve. This means that as the air slows just prior to the valve it's pressure goes up slightly thus giving a slightly increased push into the cylinder. The exact mechanism at work here seems less than completely clear but evidence indicates it to be active mostly at and just after bottom dead center just prior to flow reversals caused by the piston motion.

Down Draft Angle.

Time now to look at the effect the ports down draft angle has on optimal port size. Take a look at the illustration below.

As the port angle is flattened out so the smaller the optimal port area becomes. This is just one more factor than needs to be taken into account when designing or modifying a cylinder head for best output.

The question that immediately comes to mind here is why would the down draft angle have any effect on the optimal port area? The answer is tied to the utilization of the available valve area. If the angle is so flat (90 degrees to the valve) much of the air will, at the speed's typically reached, pass out of the valve on the long side of the port. What this means is that a 2.02 inch valve having some 3.25 square inches available is only being utilize some 75%. As far as the air and the engine is concerned that valve may as well be 1.75 diameter instead of 2.02. What this means is the port needs to be sized for a 1.75 diameter valve not the 2.02 inches that might actually exist.

What we have discussed so far begs the question as to why we have differing port sizes for what is essentially the same size intake valve. If one port area is correct why do we see results such as shown in PS #7? The reason is that there is a flow/velocity trade off that changes as displacement changes. If we had a set of perfect ports the need to change the port area (while holding the intake valve size constant) would, for a change in displacement, be eliminated. But we don't have 'perfect ports' or a situation that even allows us to remotely approach that (although the F1 guys get close). What we find is that with a less then a perfect port there is a trade off between velocity and flow. On a smaller engine the breathing characteristics are such to favor a higher velocity to combat flow reversion and aid ram filling of the cylinder. When the cylinder capacity is increased the need for ease of breathing (outright flow capability) starts to outweigh port velocity. This is why a bigger port pays off when we are dealing with production style cylinder heads that are intrinsically short of flow for the size of cylinders we are using them on.

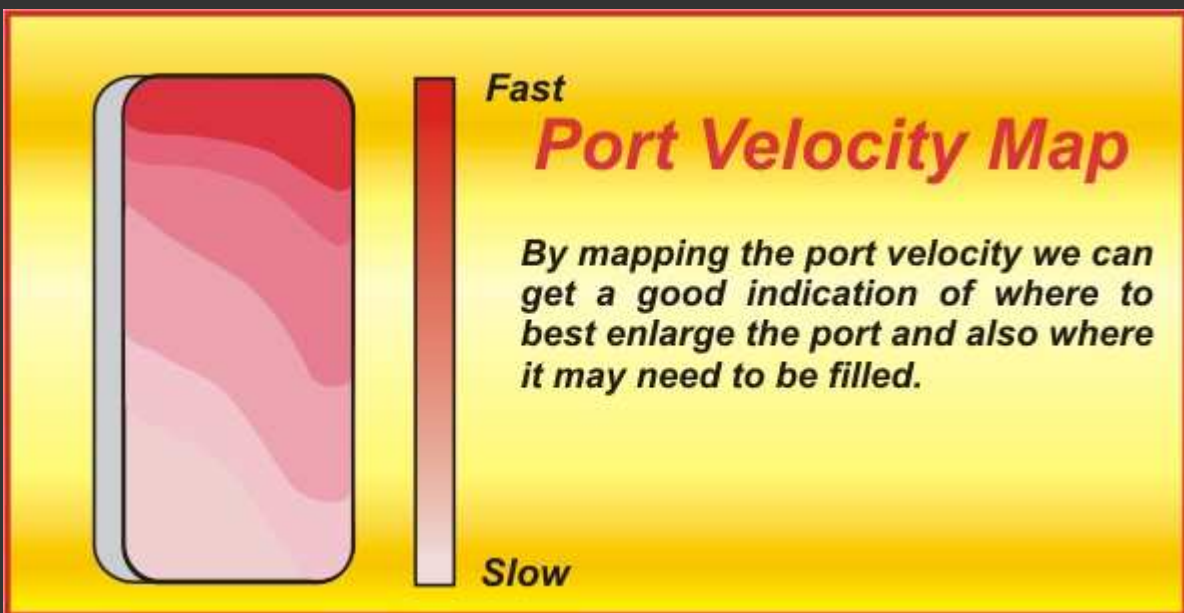
How to get the Port Size Optimal.

We are now arriving at a point where you can begin to understand that calculating the optimal port size for your particular head is at best difficult. All you can do is to be steered by the proportions I have outlined here. This is where having a flow bench pays off. By keeping a tab on flow increases in the higher lift range and monitoring the port volume you can better establish when to stop grinding on the port itself. If the volume increase starts to go up faster than the flow then it's a fair bet that any further increase in port size is going to hurt matters more than help. Always our goal is to make the port an efficient shape and this gets more complex as the original port as per the stock engine gets less like our ideal port. In the illustration below you can see how a simple round port evolves into a far more efficient form.

What you see here is a step by step evolution of an intake port in terms of shape and area. The high lift flow co-efficient of the basic round port is about 0.45 to 0.47. It's major weak

point is the tight short side turn radius. This is too sharp for the air to make it around the corner and out of the short side turn of the valve. Instead the air mostly skips across the back of the valve and out of the long side. Valve utilization is consequently poor. A small port would be all this layout could usefully use. By raising the floor of the port we improve the flow around the short side turn but in so doing the port area at the raised section is reduced more than we would want. This is especially so when we consider it also has to negotiate it's way around the guide stem and guide boss. To offset this we can widen the port so the area is more in line with what is needed. At this point we have a port that works well in a hemi having no shrouding (see PS#8). If we are dealing with a valve that is not moving away from the cylinder wall as it opens we find that best results are achieved by biasing the port so the flow at high lift is directed into the center of the cylinder. By the time we have optimized the port the high lift flow coefficient can have gone up to 0.65 or better.

At this point I have given you a set of parameters to work with but as you can see it would be difficult to impossible to give an exact area for any given circumstance unless we are working with a near ideal port. The irony here is that the F1 guys probably need a flow bench to a lesser extent than those of us porting production style heads. A key issue when modifying a port such as is typically used by a pushrod engine is to always look at the port area utilization. The diagram below shows what typically takes place in a small block Chevy port.



The airflow over any given sectional area of the ports length is far from uniform as this velocity map shows. If we assume the port is a little on the small side we can see that cutting material from the lower left hand side of the port will only have a marginal effect on flow as there is not much activity there to start with. Cutting on the floor has the effect of making the port bigger and lazier. On the other hand cutting the port in the busy area at the top is far more likely to show flow improvements. An increase in area at the top of the port can well show a proportionate increase in flow (assuming that is the port was already on the small side for the valve size and efficiency involved)

Although more in line with advanced porting let me tell you here that velocity probing the intake port most often shows where the air is going and the port needs to be cut. However there are instances where it shows just the opposite. As far as the exhaust is concerned the faster it is going the more likely it is that the place it is doing so is a good one to cut on.

The fact that a typical port does not have anything like even port utilization means that our job of port sizing comes down to having a reasonable idea of where and by how much material should be removed from any given location. If we couple this with an understanding of the limits imposed if the port was optimal in form (straight) then we are a lot better off developing an intake port that is not too big for the job. Part of you development program here is to only flow test and optimize the port size for lift values at or to about 0.05 inches higher than the valve lift to be used. The implication here is that if you have an intake port that continues to flow more and more air right up to say 0.700 lift and you valve train is only lifting 0.55 then it's a sure bet the port is too big for that particular valve train and consequently the combination being built.



What you see here is a port form for a 2¼ inch diameter valve intake port for a 2 valve head for a small block Chevy . At 0.800 lift this port flowed some 440 cfm at 28 inches. Note that the main body of the port prior to the valve guide bulge is relatively small. Also note how the port spreads in area as it turns and passes the guide boss. If the port was of a lower approach angle design it would almost certainly require the guide boss bulge to be bigger as this would help the air make the turn more effectively.

Exhaust.

We can look at the exhaust port in much the same way as the intake by starting with an idealized shape. The following illustration will give you an idea of where we are going here.

If this looks a lot like a rocket motor nozzle that's because in many respects it is. Given a reasonable up draft angle the port can, at high valve lift start to act as if it were an unrestricted (by the valve) nozzle. The result is very high flow figures through a seemingly small exhaust throat diameter.

As with the intake it is useful to look at some working proportions for near optimal shaped ports. First a generous radius coming off the seat is a great help to mid and high lift flow. Although a big radius makes the throat diameter beneath the valve much smaller the more streamlined shape is far more efficient and offsets the size reduction. Typically the under seat radius from a 0.60-0.070 wide seat needs to be about 10-12.5% of the valves diameter. This will leave the throat diameter at between 85 and 87% of the valve diameter. From here the port needs to flair out at about a 6 degree inclusive angle. All this relates to ports having a substantially narrow angle in relation to the valve. The example is shown below is of an exhaust port for a pushrod engine that falls into this category.

Note how this port looks very much like a nozzle with a bend in it. In real life it acts, at high valve lift, in much the same way. With a 1.6 inch valve the flow at 0.750 lift is over 260 cfm. With an exhaust pipe added the peak flow exceeds 300 cfm. Remember this is a near idealized form. To get the best from a port that is more a production style with a lower updraft angle we have to make compromises and generate forms that encourage the gasses to flow more easily past the guide boss and round a bend. That's where the flow bench comes into it's own!

4 Valve Heads and Intake Ports

So far we have looked at the application of proportions in terms of 2 valve engines but theses basic proportions carry over to a greater extent into 4 valve engines. We are still stuck with the fact that a real engine has a port that is far off being straight but things do get a little better. If we assume that an F1 engine has the least compromise practical then we would be looking at ports that were 25-35

degrees off the valve axis. If we consider 4 valve engines intended to fit under the hood/bonnet of a street driven machine then that angle gets to be more like 45 to 60 degrees off the valve axis. What we have to remember here is that the further off the valve axis the head becomes the smaller the optimal size port is likely to be.

In spite of the forgoing we find that most production 4 valve heads have intake ports too big for the job. Why is this – certainly if strong torque curves and absolute output is the criteria then I have to say I think a lot of designers have walked down the wrong path. Maybe it's emissions and that is something I am far from being an expert at. But as far as making power I do have experience on Cosworth DFV F1 engines and all the four cylinder derivatives of such plus the Cosworth YB (four valve Pinto). In the class I raced the latter in my engines were, in their final form, untouchable! Outside of that it's Mitsubishi, plus a little Honda and Subaru. Although not so much with the Cosworth heads it seems, in the main, that the heads for Japanese manufactures typically have ports ranging from a little to be the way to big. The heads I did for Ryan Garcia's Mitsubishi were a prime example here. The race ported head he was using was based on a casting that had ports way oversize straight from the factory and why the manufacture would do this remains, to me, something of a mystery.

In the illustration below you see the proportions of the smaller Mitsubishi port. In this instance I made a great deal of effort to improve the valves flow capability to bring it up a level that best suited the marginally too large a size of the intake port.

The illustration on the left shows the port outline of the smallest 2 liter Mitsubishi port. The center drawing shows the port outline (red) and the valve and throat diameters in yellow on the same scale. If we now look at these in terms of area (right hand drawing) we find that the straight (and very efficient) main body section of the port is actually larger in area than the combined area of the two intake valves (larger yellow circle) and certainly way larger then the combined throat area's. This is a clear indication that this, the smaller of the Mitsubishi port, is still marginally too big for the job.

The situation we are left with here is that it is more often the case that for a sporty 4 valve engine the ports are too large for the valves. We do have two options to fix this situation. First we can fill in the port and make it smaller. That's doable but there is always the worry if epoxy is used that long term it may be a problem, the second option is to install the biggest valves possible. This should be considered your primary fix. Sure it's more money but you get bigger valves and a port nearer the correct size all in one go.

David Vizard

Other parts in this series are at:-

- #1 [Porting School #1 - Why engines need airflow](#)
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In addition to the Porting School articles there are directly related cylinder head development subjects at the following sites:

Wet Flow :-

[Six Wet Flow Mistakes](#)

Combustion dynamics

#1:- [Turbulence and Combustion Dynamics](#)

#2:- [In cylinder Turbulance and Combustion Dynamics](#)

#3:- [Turbulence and Combustion Dynamics - Part 3](#)

#4:- Coming soon

#5:- [Turbulence and Combustion Dynamics - Crevice Volumes - Stealth Power Thief](#)

If you want to learn how to port heads professionally check out the site below.

Last edited by DavidVizard-GFN; 09-18-2008 at 09:12 PM.



08-24-2008, 06:19 PM

#2 ([permalink](#))

[1989GTA](#)

Tire Changer

Join Date: Oct 2007
Posts: 114

Good article David. I will have to read it through a couple of times. 😊 Would your ideal port inlet shape apply the runner in the intake manifold? Looks like what one might want to achieve in the intake manifold as an extension of the port in the head itself.

Last edited by 1989GTA; 08-24-2008 at 08:12 PM.



08-24-2008, 11:18 PM

#3 ([permalink](#))

[automotivebreath](#)

Oil Changer

Join Date: Jul 2007
Location: Southern Louisiana
Posts: 450

Hi David,
Great article, very informative.

I'm currently reworking a set of Word Products SBC 220cc intake runner heads for maximum performance, drag race application. My question is about the width of the exahust short turn, should I make the bottom of the turn as wide as possible to slow the port speed in this area?

Quote:

Originally Posted by **DavidVizard-GFN**

Note how this port looks very much like a nozzle with a bend in it. In real life it acts, at high valve lift, in much the same way. With a 1.6 inch valve the flow at 0.750 lift is over 260 cfm. With an exhaust pipe added the peak flow exceeds 300 cfm. Remember this is a near idealized form. To get the best from a port that is more a production style with a lower updraft angle we have to make compromises and generate forms that encourage the gasses to flow more easily past the guide boss and round a bend. That's where the flow bench comes into it's own!

Last edited by automotivebreath; 08-25-2008 at 12:36 AM.



08-25-2008, 02:59 PM

#4 ([permalink](#))

1989GTA 

Tire Changer

Join Date: Oct 2007
Posts: 114

David as a followup maybe an article on intake manifolds and how they interact with the intake port in the head. Maybe an article on the ideal intake manifold port?



08-25-2008, 11:39 PM

#5 ([permalink](#))

Nick 

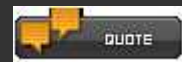
Garage Sweeper

Join Date: Sep 2007
Posts: 9

David,

Is an improvement of the down draft angle one of the reasons that the heads for the LS series of chevy engines have less valve angle than the traditional SB chevy? (15 degrees vs. 23)

Does this also explain (at least partially) why the LS1 engine's cylinder head uses a larger port (in terms of volume) than most, (if not all) production SBC heads even though the displacement of the LS1 is only 346 c.i.?



08-26-2008, 09:36 AM

#6 ([permalink](#))



DavidVizard-GFN 

Pit Crew

Join Date: Apr 2007
Posts: 840

Quote:

Originally Posted by **1989GTA** 

Good article David. I will have to read it through a couple of times. 😊 Would your ideal port inlet shape apply the runner in the intake manifold? Looks like what one might want to achieve in the intake manifold as an extension of the port in the head itself.

The idealized port shown represents a port from beginning to end. consider that the engine has no idea how much port is contained in the head and how much in the manifold.

DV



08-26-2008, 09:40 AM

#7 ([permalink](#))



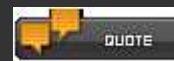
DavidVizard-GFN OFF

Pit Crew

Join Date: Apr 2007
Posts: 840

AB,
Regarding the width of the port on the short side turn. Ther answer here is in essence yes but other factors can weigh in so making a blanket statment is not really a good idea. The bowl does need to widen out somewhat so this does tend to leave the floor on the short side wider and flatter. Bottom line is be guided by the bench!!

DV



08-26-2008, 09:41 AM

#8 (permalink)



DavidVizard-GFN OFF

Pit Crew

Join Date: Apr 2007
Posts: 840

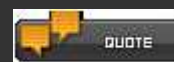
Quote:

Originally Posted by **1989GTA** ➤

David as a followup maybe an article on intake manifolds and how they interact with the intake port in the head. Maybe an article on the ideal intake manifold port?

We will get to manifolds but not just yet - there is a ton of stuff on heads yet to be covered.

DV



08-26-2008, 09:49 AM

#9 (permalink)



DavidVizard-GFN OFF

Pit Crew

Join Date: Apr 2007
Posts: 840

Quote:

Originally Posted by **Nick** ➤

David,

Is an improvement of the down draft angle one of the reasons that the heads for the LS series of chevy engines have less valve angle than the traditional SB chevy? (15 degrees vs. 23)

Does this also explain (at least partially) why the LS1 engine's cylinder head uses a larger port (in terms of volume) than most, (if not all) production SBC heads even though the displacement of the LS1 is only 346 c.i.?

Tricky question here.

Can't vouch for it but let me tell you what I heard. The tall LS1 thru 6 port was used because it generated a swirl /fuel spray interaction that cut emissions. The chamber was flatter so that there were less end gases trapped in a wedge and that the quench area, which can raise parts/million HC, is less. That,s all I can tell you. Bottom line is it seems to have little to do with output. Anyone else got any comments here???

DV



08-26-2008, 01:25 PM

#10 ([permalink](#))

1989GTA
Tire Changer

Join Date: Oct 2007
Posts: 114

"The idealized port shown represents a port from beginning to end. consider that the engine has no idea how much port is contained in the head and how much in the manifold."

That is what I was thinking that the picture could actually represent the whole intake tract including the intake manifold.



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