Induction Systems

Common Terms

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Plenum

The plenum area is where the intake runners meet. There can be one plenum that all runners meet, or two smaller plenums with 1/2 the runners meeting in each. The plenum volume is a very importing tuning aid. As high velocity gasses flow through the carburetor or throttle body, the plenum give the gasses a chance to slow down, as the velocity is reduced the pressure rises. Higher pressure means that the air will be denser, and of course that means more power.

As rpm goes up you need a larger plenum, but a larger plenum will reduce throttle response and low-end power. A plenum also reduces peak air velocity through the carburetor (or throttle body). The induction pulses in an intake cause velocity to rise and fall with every pulse. The plenum helps to reduce them by acting as an air capacitor. Average velocity will remain the same, but the highs and lows will be closer together. Since you need a carburetor that will flow enough air at peak velocity, a larger plenum will allow you to run a slightly smaller carburetor without losing airflow, but it will also reduce the peak signal strength, which is why large plenums tend to reduce low-end power.

Helmholtz Resonator

A Helmholtz Resonator is the theory behind what happens in the intake (and exhaust systems). Induction pressure waves can have an effect on how well the cylinders are filled. Carburetors that have velocity stacks in each barrel are taking advantage of this; it can help (or hurt) power in a narrow rpm range. For more information see the Helmholtz section below.

Intake Runners

These are the connections between the cylinder head and the plenum area. They must flow enough air at peak rpm to support the horsepower your engine is capable of, but not be so big that they have extremely low velocity at low rpm. The runner length is also very important if the induction pressure waves are to be used to increase volumetric efficiency. Runner taper is also important to consider (see the Tuned Port Section below) for more info).

Carburetor Spacers

These are probably the most misunderstood things there are. It seems that almost everyone installs one on his or her engine. Most people know that it helps top-end power, but they don't really know why. The answer is, it increases plenum volume, which reduces the induction pulses at the carburetor and brings the peak velocity through the venturi down.

Most manifolds are made with plenums that are too small, so adding a spacer will usually help. Manifold companies know that the plenums are too small, but it is easier to add a spacer if it's too small, than to remove space if it's too big. Just about every engine design will be offered at different displacements. So a company must design a plenum to work well with the smallest displacement engine available or make sure that is marketed toward larger displacement or higher revving engines.

Individual Runners (IR)

Individual runner manifolds have no plenum. There is one throttle bore per cylinder and nothing connects with anything. These offer the best signal strength at low rpm, because the have the highest peak velocity through the throttle bore, but are very hard to tune in and induction pulsing at high rpm is a big problem.

Due to the high peak velocity, IR set ups need a lot of airflow capacity. The basic carb sizing formula does not apply here. There could be 2500 CFM on top of a 350 cubic inch engine and it could run fine. This is because each throttle bore gets an induction pulse once every two engine rotations, so it's only in demand about 25% of the time. Plenum type set ups will allow other cylinders to use that throttle bore while other cylinders do not need it, so you don't need nearly as much airflow capacity.

Tuned Port

When a port is the correct length to add volumetric efficiency by utilizing the induction pressure waves, it is said to be tuned. This can only help over a narrow rpm range (see tuned port basics below for more info).

Manifold Heat

Most production manifolds will have some sort of exhaust or coolant passage in it to heat the intake. This helps fuel atomization, but hurts top-end power. Cooler air is denser and denser air makes more power. Any kind of performance engine should not use manifold heat. Manifold heat does help low-end and fuel mileage by aiding in a more efficient burn.

Venturi

An hourglass shape in a carburetor that causes the air to increase velocity as it passes through the narrower section. As velocity increases, pressure decreases. This is how a carburetor flows fuel. The pressure in the venturi will be lower than the pressure in the fuel bowl, so the higher pressure will push fuel through the carburetor. This is the simple principal of pressure differential, which relates to many things in an engine.

Booster Venturi

This is where the fuel enters the venturi and it is fact another smaller venturi itself. Its main purpose is to further increase the speed of the air and in turn lower it's pressure even more to gain more signal strength. There are many kinds of booster venturi; the ones that give the best signal strength and atomization are usually the most restrictive to airflow.

Signal Strength

This directly related to venturi size, shape, booster venturi, and air speed though the carburetor. The signal strength is how much the venturi can reduce pressure. A large venturi will have less signal strength than a smaller one, but will also flow more air. If the venturi is too big, it will have a hard time metering fuel at low rpm, if it is too small, it will be a restriction at high rpm. This is why larger carburetors need larger idle feed restrictions and jets. Not necessarily because the engine needs more fuel, but the lower signal strength needs larger passages to flow the same amount of fuel.

Dry Flow Intake

With fuel and air traveling through the intake, sharp corners can lead to problems as velocity increases. Air is lighter than fuel and can take sharper turns. As an air fuel mixture goes around a sharp turn, the fuel separates and flows along the outside of the turn.

Getting intake runners long enough to help low to mid range torque is hard to do with limited hood clearance. Multi-port fuel injection lets us inject fuel right at the intake port of the head, which leaves the rest of the manifold flowing only air. By doing this, we can have some sharper bends. Air still flows better in a straight line, but not having fuel separation is a big plus.

The GM TPI manifold is a good example of a dry flow manifold. There is no fuel in the runners until right before the heads. The runners come out of the plenum and cross to the opposite side of the engine, making them long enough to help low-end and still give hood clearance.

Wet Flow Manifold

They flow air and fuel of course. Carburetors and throttle body injection are wet flow systems. The intake runner shape is much more critical because it must minimize fuel drop out. Wet flow system designs are much more limited due to this.

Source: www.grapeaperacing.com

Types of Intake Manifolds

Dual Plane

This type of manifold has a divided plenum (or two smaller plenums). It is a good choice for low rpm power and gives better throttle response than most other manifolds. The small plenum area gives good carburetor signal strength and low-end drivability. Dual plane manifolds generally can tolerate larger carburetors than similar open plenum manifolds.

Single Plane

Also known as 360° manifolds or open plenum. All intake runners come form a common plenum. The open plenum smoothes out the induction pulses better than a dual plane manifold and can give better top-end power, at a cost of low rpm power. The open plenum reduces peak velocity through the carburetor, which reduces signal strength. If you have a high revving engine, a single plan would probably be the better choice.

Tunnel Ram

Really this is just a more exotic version of an single plane. All the intake runners are straight and meet at a common plenum (the tunnel). This type of manifold gives excellent fuel distribution and flow for top-end power. The large plenum area reduces signal strength and throttle response, so it takes some good tuning to make these responsive for street driving.

When tuning in one of these, you'll need a quick accelerator pump and more ignition timing down low. In most cases, you can lock your distributor to total advance. You might need a retard box to retard the timing while you start it, but for the most part tunnel rams run best with a lot of advance at an idle. If you want an advance curve on a street tunnel ram set up, use a vacuum advance and hook it directly to manifold vacuum. The poor mixture at low rpm requires a lot of timing at idle and cruise conditions.

Many people will argue that tunnel rams are a race only, high rpm manifold, but this is not really the case. They have worked very well on street engines and when tuned right will almost always out perform a single plane manifold across the rpm range. I have seen many back-to-back dyno pulls where a tunnel ram beat single plane manifolds.

Individual Runners (IR)

This type manifold has one throttle bore per cylinder. It enhances low and midrange power by increasing peak velocity through the venturi. There is no plenum to dampen the induction pulses, so it is difficult to get them to work at high rpm (It is common for fuel to splash out of the throttle bore at high rpm).

The carburetion is also very critical, a IR set up will need each throttle bore to flow enough for peak airflow. This means a 350 cubic inch engine can have almost 3000 CFM and not be over carbureted. If this setup is used with dual 4 barrels (Holley dominators are common), you'll need to make the linkage a 1:1 ratio so the secondaries open at the same rate as the primaries.

Cross Ram

Mostly used on bigger cars to help low to mid rage torque. The long runners can help low-end power. Hood clearance can be a problem with long runners, so by crossing the runners to a carburetor located on the other side of the engine, they can be longer but not higher. This was common with older Mopars and worked very well for its time. Fuel drop out was a problem, so these set-ups generally ran rich at low rpm and sucked up gas. Long runners with a wet flow system give the fuel more time to form into large droplets at low rpm.

Tuned Port

Tuned Port manifolds can come in various shapes and forms. They are usually associated with fuel injection, but the Tuned Ports idea is not related to EFI at all. Tuned port simply means that the intake runners are tuned to a specific rpm range.

Most factory tuned port set up are sized to help mid range torque. The Chevy TPI works very well in the 3000-3500 rpm range. The problem with them is they run out of air by 4500 rpm due to the small runners.

Intake Manifold Basics

Source: www.grapeaperacing.com

Function

The basic function of the intake manifold is to get the air form the carburetor or throttle body directed into the intake ports. It may seem like a simple thing, but what really goes on inside is quite complex. The design of the intake manifold will have a significant effect on how the engine runs.

Airflow

Getting air into an engine is the key to making power and there are many ways to increase the air flow into the engine, some are obvious and some are not. Other than forced induction and nitrous, there are 3 ways to increase airflow. The first is obvious, better port and valve shapes to improve flow.

The second and less realized is harnessing the inertia of the airs velocity to better fill the cylinders. This is why cams keep the valves open before TDC and after BDC. If all the induction parts are matched to the same rpm range air can continue to fill the cylinder even as the piston begins to move upward. This is due to the speed of the intake charge giving it inertia to resist reverse flow, to a point.

The third and not known to many people is induction wave tuning, this is related to inertia tuning, but is more complex and more difficult to tune to a specific rpm range. Induction wave tuning is why tuned ports work so well.

Porting Goals

Your goal with any port modifications should be to get as much flow and velocity as you can with as little restriction as possible. When working on a flow bench, pay close attention to how much metal you remove and how much the port flows. If you have a 100 cc port that flows 100 CFM, then you modify the port by grinding 5 ccs of metal away and the port now flows 110 CFM, you gained flow and velocity (a good thing for a street engine). If your modified port flows 103 CFM, you gained a little flow, but lost velocity.

You will need to cc the ports often and measure flow often to get good results. If you don't have access to a flow bench, it's best to remove as little metal as possible. Most pocket porting jobs give very good results when less than 5 cc's of metal is removed. More than that, you need a flow bench to see if what you're doing is helping or hurting.

Port Shape

Any sharp edges or corners make a restriction to airflow. Air is light, but it does have mass and will flow better if it does not have to negotiate sharp corners and around obstacles. With a wet flow manifold (fuel flows through the manifold as well), sharp turns in the manifold will cause fuel separation at higher rpm. Fuel is heavier than air, so when a fuel are mixture flow around a corner, the heavier fuel will not be able to turn as good as the lighter air.

If you look at a basic 4-barrel intake manifold, the area directly under carburetor has a sharp turn. The air flows straight down through the carburetor as then has to take an almost 90° turn to get to the cylinders. At high rpm the fuel has a hard time staying mixed with the air and can puddle on the port floor.

Another thing that causes fuel separation is low velocity. This is especially a problem with large ports at low rpm, the lower the velocity is, the more time the fuel has to drop out. Fuel is heavier than air, so the longer it has to separate, the more it will. Getting high velocity is very easy, but getting it without making a restriction is a little more difficult. You need large ports to flow well at high rpm, but large ports will decrease velocity and hurt low-end power.

Port Polishing

Polishing the intake ports can show slight improvements in airflow, but can hurt power. A rough texture will make some turbulence at the port walls. Fuel has a tendency to run along the port walls, especially on the outside of turns and the floor. A rough texture will help keep the fuel suspended in the air. Unless you really know what you’re doing, don't polish the intake ports.

Tuned Port Basics

Source: www.grapeaperacing.com

Induction Waves

Lets first look at what happens in the manifold to better understand how to use it to our advantage. When an engine is running, there are high and low pressure waves moving in the manifold caused by the inertia of the air (as well as exhaust) and the opening and closing of the valves. The idea of port tuning is to have a high-pressure wave approach the intake valve before it closes and/or just as it opens, forcing in a little more intake charge.

Pressure Wave Causes

The most commonly known cause of a pressure wave is the piston as it moves down the bore. On the intake stroke, the piston makes a negative pressure wave that travels form the piston toward the intake tract. Once that negative pressure wave reaches the plenum area, it is reflected as a positive pressure wave That positive pressure wave travels back toward the cylinder. If it reaches the intake valve just before it closes, it will force a little more air in the cylinder.

The second, less realized, cause of pressure waves is the exhaust. If you have a good exhaust system that scavenges well, during the overlap period there will be an negative pressure wave as the exhaust is scavenging and pulling in fresh intake charge. The same thing happens, it travels up the intake and is reflected at the plenum area as a positive pressure wave. If the intake runner length is correct for the rpm range, the positive pressure will be at the valve just prior to it's closing and help better fill the cylinder. This will also help by reducing reversion with long duration cams. To get the benefits form this you need a well tuned exhaust system.

The third and most complex cause of pressure waves is when the intake valve closes, any velocity left in the intake port column of air will make high pressure at the back of the valve. This high-pressure wave travels toward the open end of the intake tract and is reflected and inverted as a low-pressure wave. When this low-pressure wave reaches the intake valve, it is closed and the negative wave is reflected (it is not inverted due to the valve being closed), once again it reaches the open end of the intake tract and is inverted and reflected back toward the intake valve. This time the valve should just be opening (if the port is tuned to the rpm range) and the high-pressure wave can help.

Pressure Wave Speed (V)

The pressure waves travel at the speed of sound. In hot intake air it will be about 1250 - 1300 ft. per second. Engine rpm does not effect the speed of the pressure waves and this is why induction wave tuning only works in a narrow rpm range.

Combined Effects

On a well tuned intake set up there will be a high pressure wave at the intake valve as it's opening, at the same time the engine should be in its overlap period (both valves open). If the exhaust is tuned to the same rpm range as the intake, there will be low pressure in the exhaust (due to scavenging) at the same time. Since the intake port near the valve is higher than atmospheric pressure and the cylinder is a great deal lower, the air will start to fill the cylinder quickly. The higher-pressure area will quickly drop in pressure as the piston travels down the bore; this creates the low-pressure wave that travels away from the cylinder. Just as this starts to happen, the piston starts moving down the bore creating another negative pressure wave, so there is actually two negative pressure waves, one right after another.

In a well tuned intake system there can be as high as 7psi of air pressure at the intake valve due to these pressure waves and sometimes even higher. So you can see that it can have a very large influence on the volumetric efficiency of the engine. This is how a normally aspirated engine can exceed 100 % volumetric efficiency.

Reflective Value (RV)

Getting an optimum runner length may be hard to do due to engine compartment space and/or the engine configuration. A small cammed engine operating at lower rpm will need a long runner length, so instead of trying to fit such long runners under the hood, you can just tune the system to make used of the second or third set of pressure waves and make the system much shorter.

Intake Runner Length (L)

Knowing that the pressure waves (positive or negative) must travel 4 times back and forth from the time that the intake valves closes to the time when it opens and the speed of the pressure waves, we can now figure out the optimum intake runner length for a given rpm and tube diameter.

We must take into account the intake duration, but you want the pressure waves to arrive before the valve closes and after it opens (air wont pass though a closed valve). To do this you must subtract some duration, typically you take off 20-30° from the advertised duration. 30° works well for most higher rpm solid cammed drag motors. So the Formula to figure effective cam duration (ECD) will look like this:

ECD = 720 - (Adv. duration - 30)

For a race cam with 305° of intake duration it will look like this:

ECD = 720 - (305 - 30)

The ECD of that cam would be 445. The formula for optimum intake runner length (L) is:

$L = ((ECD \times 0.25 \times V \times 2) \div (rpm \times RV)) - ½D$

Where:
ECD = Effective Cam Duration
RV = Reflective Value
D = Runner Diameter

If our engine with the 305 race cam needed to be tuned to 7000 rpm using the second set of pressure waves (RV = 2) and had a 1.5" diameter intake runner the optimum runner length formula would look like this:

$L = ((445 \times 0.25 \times 1300 \times 2) \div (7000 \times 2)) - 0.75$

So 19.91 inches would be the optimum runner length if the system is tuned to the second set of pressure waves. 19.91 inches is a very long runner, which may not be easy to package under the hood of most cars. It would probably be a better choice to use the third set of wave reflections, which is what is often used in NASCAR engines.

Intake Port Area

Unlike intake runner length which effects power over a narrow rpm range, the size (area) of the runner will affect power over the entire rpm range. If the port is too small it will restrict top-end flow and flow, and if it's too large velocity will be reduced and it will hurt low-end power. The larger the port is, the less strength the pressure waves will have.

Since the intake valve is the most restrictive part of the intake system, the intake runners should be sized according to how well air can flow through the valve area. Most decent heads will have an equivalent flow through the valve area as a unrestricted port of about 80% of the valve area, this is if the camshaft it matched to the heads. In other words a 2.02" valve, which has a 3.2 square inch valve area, in a decent flowing head will flow the same amount of air as an open port with about 2.56 square inches of area (80% of 3.2). So the port area should be about 2.56 square inches just prior to the valve (this is in the head port). Some well ported race heads may have an actual flow of an area up to 85%, but for the most part it is around 78-80%.

Intake Port Taper

To further help fill the cylinder, it helps to have a high velocity at the back of the valve. To aid in this the intake port can be tapered. To be effective, there should be between 1.7 and 2.5% increase in intake runner area per inch of runner, which represents a 1-1.5 degree taper. For an example, lets say you're looking for a 2% increase per inch taper on the 2.02" valve we discussed earlier. We already came up with a port area of 2.56 square inches at just before the valve. Now lets say the total runner is 10 inches from the valve to the plenum and we're looking for a 2% per inch taper. This turns out to be a total of 3.12 square inches where the port meets the plenum. As you get near the 2.5% per inch taper point, you are pretty much at the limit of helping airflow. A larger taper will only hurt signal strength at the carburetor.

Source: www.grapeaperacing.com

The Helmholtz Theory

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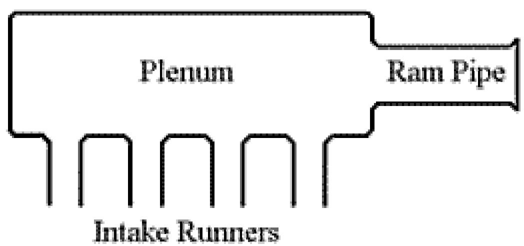
Helmholtz's Theory

The idea here is to continue to use the tuned port advantages in the plenum and intake pipe. Actually, tuned ports are Helmholtz resonators themselves. This section will just take that system further up in the intake track.

To make it simple, lets say that there is one throttle bore for a 4 cylinder engine. There will be 2 induction pulses through the throttle bore per revolution. When the air pulses through the throttle bore, is causes a negative pressure wave traveling through the intake pipe. Once this pulse reaches the open end of the pipe (usually at the air cleaner housing), it will invert to a positive pressure wave. If we can time this wave to arrive back at the plenum to boost pressure when it's needed the most, we may see a power increase.



The Helmholtz resonator theory does work well, however, it is limited to how many cylinders can operate off a single plenum. To be effective, no more than 4 cylinders should be used in a single plenum. This set up is very effective on 6 cylinder engine with two plenums, each plenum feeding 3 cylinders. To make matters worse, the cylinders must be even firing, so simply dividing banks of a V6 or V8 will not work unless the banks each fire evenly. For a V8, the best solution is to use a 180 degree crankshaft to even out the firing order of each bank. Then the Helmholtz resonator can be applied as if it were a pair of 4 cylinders.

It is possible to see small gains at low rpm with using one plenum for 8 cylinders, but this will usually lead to a reduction in top-end power. There are 3 tunable aspects of the Helmholtz resonator, the plenum volume, intake ram pipe, and intake ram pipe diameter.

Intake Ram Pipe Diameter

This is the easiest to figure out. The velocity in the plenum intake pipe should not be higher than 180 ft/sec at maximum rpm. The formula to figure out the diameter pipe that should be used is for a given velocity is:

D = ^(CID × VE × RPM) ÷ (V × 1130)

Where:
D = Pipe Diameter
CID = Cubic Inch Displacement
VE = Volumetric Efficiency
V = Velocity in ft/sec

If you're dealing with liters, change CID to liters and the constant to 18.5 so the formula will look like this:

D = ^(Liters × VE × RPM) ÷ (V × 18.5)

An example for a 153 cubic inch 4 cylinder with a 85% VE, revving to 6000 rpm would and a desired 180 ft/sec air speed though the intake pipe would look like this:

D = ^(153 × 0.85 × 6000) ÷ (180 × 1130) = 1.96

You would need an intake pipe that has a 1.96" inside diameter to have 180 ft/sec air velocity at 6000 rpm for that engine. In other words the engine would need a little over 3 square inches of intake pipe area.

Plenum Volume

There is not going to be a simple answer to the needed plenum volume for a given application or rpm range. The good thing about plenum volume is that there is a pretty wide range that it can be and still be effective, so general rules work well. The following guidelines are for engine operating in the 5000-6000 rpm rage.

V8's with one large plenum feeding all 8 cylinders does not work all that well as far as the Helmholtz resonator goes, but if this is the case, plenum volume should be about 40-50% of total cylinder displacement. On a four cylinder engine 50-60% works well. For 3 cylinders (6 cylinder engine with two plenums), each plenum needs to be about 65-80% of the 3 cylinders it feeds.

If a boost is desired in a higher rpm range, closer 7000-7500 rpm, the plenum will need to be 10-15% smaller. To get a boost in the 2500-3500 rpm range, it will need to need about 30% larger. The plenum size of a Helmholtz resonator may go against the typical plenum size rules, but the rules change when the resonator is being used. The whole Idea of a plenum is to allow the gases to slow down and gain density. The Helmholtz plenum makes a dense charge by use of pressure waves, in the same way tuned port intake runners work.

This plenum sizing method does not apply to engines that to not use a tuned intake pipe. Many engines simply have the air cleaner assembly directly on the carburetor or throttle body having very little intake length. In those cases the Helmholtz resonator system does not work.

Intake Ram Pipe

The last thing to adjust is the length of the intake ram pipe. It is possible to make an adjustable pipe that can be made longer or shorter for testing purposes. For a starting point figure a 13" long pipe will help at about 6000 rpm. For each 1000 rpm drop in rpm add 1.7" and subtract 1.7" per 1000 rpm increase. This is just a starting point.

The inlet of the pipe should have about a 1/2" radius for smooth flow. Once you get a baseline (you must do a power pull and get a baseline), which can be done at the track or on a dyno. Then try moving the pipe 1/2" in either direction as see how power improves. The dyno may be a little deceiving, since peak hp my go up but average power may drop. Track testing will be best, since you will be testing in actual racing condition and can tune the pipe for the best times. It is usually best for average power if the intake ram pipe is tuned about 1000 rpm lower than the intake runner length.

Multiple Ram Pipes

Most engines will have more than 1 throttle bore feeding the cylinders. In this case you must figure out the total area of intake pipe needed to figure out what size each pipe should be. In the first example, the 4 cylinder engine needed a 1.96 diameter intake ram pipe. If that particular engine had a two barrel carburetor (or two single barrel carburetors), you would need two pipes each one having 1/2 the area of a 1.96" pipe.

First off, a 1.96" diameter pipe has a total of 3.02 square inches. So we're be looking for pipes that each have 1.51 square inches of area. Using the formula for finding the area of a circle in reverse, you come up with 1.39" diameter. So a pair of 1.39" diameter pipes will act the same, or very similar to a single 1.96" pipe.

Source: www.grapeaperacing.com