The principle that is at work in a merged collector is this. The smaller the choke the longer it takes for atmospheric pressure to equalize into the back door of a given engine. It protects your power curve the same way as shorter cam timing and longer primary tubes. Just slipping a collector on with a smaller choke will usually show more power at the bottom of the curve. (which Joe points out)..
The secret is that you can now shorten your header which is how you can make more power upstairs.

Header length is always relative to rpm band but also the size of the choke. Most headers have to be long because the collectors are so large. The longer tubes keep the reflected wave "back" at the lowest point on the power band that the engine has to pull from. Change the collector choke and shorten the tubes and you will see the power. If you can't shorten the tubes, do not blame the collector, and if you need shorter headers, call me...

I am using Joe Sherman's example as what will happen just installing on a existing header. If you can not shorten your header or get one shorter for your application, Joe is absolutely correct, they are expensive and are not a solution in themselves.

I don't think that is off topic at all. Back in the old days, (50's through the 80's) bigger headers, (bigger everything for that matter), the introduction of Superflow dynos to the average engine shop along with the "flow bench" in the hands of anyone with a grinder...the quest was for the maximum hp at the top of the curve. The loss of bottom end power was ignored when you could make a big increase upstairs. In most types of racing during those periods, the increase was definitely there and measurable at the track. Over the last 20 years or so, we have found,(with I'd like to think some input from me) that we only have to make things like headers as big as they need to be, in fact the work is in finding out how small can we make the back-door of an engine without losing power. This is much more to do with flow than tuning. When we find that a 1.75" tube on a 6" radius can flow the same as a 1.88" tube on a 3" radius it should change how you build headers, not to mention how large the exhaust port needs to be at the exhaust flange where the header starts...

The essential realization that seems missing (to me) from tuners' understanding of the function of an exhaust system is, the larger you make a given system, what you are doing is letting the the full weight of the atmospheric pressure get to the back of the engine sooner and easier. This no longer the way to make more power. If you can see a choke on a merged collector as a valve or orifice through which the atmospheric pressure has to traverse to get to the engine, you may see that the thing to work towards is how small a choke can we get a given engine's exhaust gases through before you start losing power. And another thing to keep in mind is that in most applications I have seen, decreasing choke diameters (and the whole header for that matter, ie smaller and shorter tubes) is not a flow issue but rather a engines inability to deal with the reduction in pressure it sees on the exhaust side for the given cam timing. I think it is important to remember that only one cylinder is firing at a time, whether you like it or not. When I was able to reintroduce a 421 header design in Winston Cup back in the middle 90's, we quickly learned that **ANY**421 header could use at least a 1/4" smaller final collector choke while making more overall power. Having been learning about the ins and outs of this for many years, I can not help but have to look at the exhaust port itself and what I am given to work with from my customers in terms of

area's. There are quite a few cylinder head guys out there that have heard my spiel, some respond and some don't but the bottom line is that I have never seen a exhaust port that I liked. An exhaust port needs to be designed from the point of view of the whole header design and system that it will be using.

I am going on because your post just puts forward the grand confusion around exhaust valve vs header size and how it all works. Thanks for the input.

If you keep dropping the pressure in the header, and that is not hard, you will eventually get to the condition which you are seeing which is overscavaging. Changing the camshaft around is effectual only to the degree that it was too large or too tight in the beginning.

Lets try stepping back further from the situation. There is a basic amount of duration you need to get to a certain rpm and power level with a given engine combo. There is a wall there that you hit when your just dropping header pressure and correspondingly reducing exh duration and overlap, (and all the other tricks there are). It does not allow you to really make too much more power with the same size intake valve. It is a diminishing return. The adjustment is to reduce the size of the exhaust valve. This allows you to keep the duration or cam timing where it really wants to be and still exhaust well enough. The smaller exhaust valve allows most engines to use a larger intake valve and this is the ultimate purpose in using a properly tuned header. The well tuned exhaust side allows a larger intake valve which is the easier way to move more air into the cylinders than sucking from the back door. If your header is not functioning well, you will not be able to get there. 
Very few engine people get this.
I believe if you look at PS type 2valve engine development over the last 10 years, you will see a very large increase in power and rpm, but exh valves are the same or smaller in diameter and the intakes are larger.The merged collector and corresponding header and valve sizing has been a important factor.

I look at the area of the port at the flange intersection and just because the manufacturer made a given port 3.5 or 4.5" long is not because they understood about stepping headers or much of anything for that matter.

For all engines, I want to match the port area with tube area, and leave any excess (but hopefully none) tube area on the bottom. Under 8k rpm limits, the first step is as much as 10" out. On 10500rpm engines, the first step is about 3-4" out.
Last point I would make is a needle at head porters, the port should be as round as you can possibly make it and sized to the tube area you want to run off the head.
No matter how fancy the port is or how much it flows, the header tube is **round** and putting a larger tube on it hurts velocity which is a important part of the exhaust equation when trying to get the header to help you make more power and broaden the power band.

It helps to not think in terms of "port" verses "tubing". The tube becomes the port. You do not introduce tight radius for the same reason you do not do it in the ports. The only way to overcome the loss, especially in the transition area and the first 6-8" of the header, is by using larger tubing diameters.

And the problem keeps going down the toilet. "Well, if we made a bigger header, it would make a little more power",(because we overcome the flow loss up front). But the larger tube now needs an even tighter radius to clear the obstruction... And you are now so far away from what the engine wants for a header, it really does not matter what you do from there, the engine won't respond to changes.

The smallest diameter tube allows for the largest radius. It can even be smaller in area than the port, especially if it allows a larger radius. (the application can trump this though)

The first 6-8" of the header is just as important as the first 3 or 4" in the cylinder head. The same rules and thinking that a head porter uses apply to the header. Most headers I see break all the rules.

The last thought is this, the reason the first 10" of the exhaust track is so important as opposed to just the port in the casting? The gas particles, the mass...only gets that far before the ex valve closes behind it, and it no longer is connected to its pressure differential, if you will. At that point in the exhaust track, everything changes. But anything you do to the "particulate-mass" flow in the port while the valve is open that violates flow, will cost you power and you can not get it back. You want to get the "mass-flow" as far away from the ex valve and the cylinder as you can. Larger "anything" in this area does not usually help.

I do understand that many applications force the header to break all these rules and larger is the only answer if you need maximum power.

I would not be afraid at all of using 1.625 at all off an even larger port area. I do it all the time for Cobra Automotive and their nostalgia mustangs and cobras. 1.63@8-1.75@10, 2" secondary for 12-14", (not a typo) and a 2.25" choke at the final collector. 620hp no problem and all sorts of bottom end. Especially for such a small motor and road racing. I do not know what or how PipeMax decides how to set length of a primary on a 421 header. Maybe some day I will get a chance to look. The problem is that a 421 header essentially tunes twice and knowing how the two relate is from experience. Two headers in one is a bit tricky math. IMO

just do not swage the tubes on the top ok? Let the roof of the port be smooth into the top of the tube, let the bottom come up to the diameter. If the area reduction is more than 12-14% I would stay with the 1.75 and just use it at 18", no step. (does not need it for that power level) and tell the customer that on the next motor don't let the head porter near the exhaust port for very long, eh?... 

Last point, the 421 header and smaller chokes on 4into1 headers has negated the need for the "anti-reversion" step commonly used back when, in order to get the large header referred to in a previous post on this thread...

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ok, if you can use a larger radius anywhere and you can get it, use it.

I would rather use two 6" radius sections than a piece of straight with a 4" bend to go the same distance and angle change. You also have to look at the whole tube and tube pack. If using larger radius off the head forces you to use a really tight radius on one or two tubes near the collector?... the application and experience helps me decide which one in that case was more important, it is a delicate balance and a art.
And in case anyone might be wondering, yes, I will allow a tube to be shorter if it has more bends in it than the rest of the tubes on a average, and vice-versa

When I was first starting out, there was only one outfit in America where I could get 1.88" tubing bent on a 6" radius.
He was so proud of them I paid a more friendly tube bender to get the tooling so I could have my own source. Now they can be gotten about anywhere with benders that cater to us header guys.

A current SB or BB Prostock type header I build uses 6" radius off the head on 6 of the 8 pipes. 80% of the bends in the header are 6" radius.
This is the most important part of a header to me.

When the tube is smaller than the port, you have the ability to design the flange so as to put the excess tubing area where you want it. It goes on the bottom.

It should come as common thinking that the port should be sized to available tubing sizes. Any head porter that does not take that into consideration when looking at the exhaust side should be avoided. IMO. Obviously if the casting was designed with a weird shape there is not much you can do, but there is no excuse, IMO, for a port to not be round and the same diameter as the id of tubing, does not matter what the flow bench says. If you don't make it round, I will...in less than 1/2". Machined flanges that make the transition are an answer but I know very few people that will go to that expense except Cup and F1).

And using a 1/2" or 3/4" thick adapter on the head may seem a nice answer, it isn't if you have to use a tighter radius to clear things you are now that much closer to...

You are going to have to be a bit humble here, I would have to say that the power loss is because of the multitudes of bends, welds and probably mismatched joints and tight radius. Flow is a major part of the issue as rpm's climb. The "cheap" headers use pre-bent tubes and are a good % smoother overall than yours. It is easy to build a big header for a given engine but try and get tube size smaller and you have to be very careful or you will lose power. You simply can not have so much bends and welds so close to the engine. Sorry, but that is what I see here.
Collector sizing is probably the biggest player in this combo and its effect on fuel curve. The best BSFC is more important to me on the dyno than actual power numbers.
If 421 are allowed, it is a no brainer and I would stay at 1.625 for 10", step to 1.75 for 7" then 2" secondary at about 12-14" after the collectors. Final choke wouold be about 2.125"-2.25" with a megaphone out to 2.5" for what ever it takes to get to a final 2into1 with a 2.75 choke and taper out to a single 3"pipe.
A 4into1 header would step once and be about 30" with 2.375 or 2.50 choke collector and still a 3" tailpipe. I don't think the distance between the final header collectors and the final 2into1 for the tailpipe makes too much of a difference, (although I am sure dyno-racers would argue) just don't make that length longer than it has to be.

Also make sure the id of the muffler is actually 3" ID, you would be amazed.!

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probably the biggest player in regards the second question is the size of a choke in the header final collector. Most collectors are way too large and allow the "stuff" in the system to more readily effect the work of the headers before the collectors. An example is say a 350SB Gen1 Camaro at say 500hp at 7500rpm engine. With a 421 header the final choke would be around 2.25" OD, a 4into1 about 2.5", while a off the shelf header would be 3.0,maybe even larger...uugghh. Anyway, the smaller chokes act

as a valve or back door if you will and helps isolate the front from the back. It makes a very big difference keeping the back door shut!

The smaller the hole the happier the engine is at lower rpms and makes much more power without losing any upstairs . Can anyone see why the 421 header can put a big grin on your face?...

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just want to say that I do not build a header any different because it has a system behind it. If there is not a system then I can use a megaphone and reverse cone to attenuate the pressure waves and pull even harder on the engine. A full system only increases flow resistance from my point of view and will take power from the very top of the power curve if at all.

A properly sized header is right all the time and is not as sensitive to what is behind it. With all respect to past ventures in exhaust header and system design, if you look backwards, you lose!

I always build 4into1 headers with rotating firing order. period. Pretty much saw that little helper in cup engines way back in the early 90's. The issue is flowing gases through a hole. They do better going around in a circle! The first secret is that if you work at it you will find out that you can run a smaller choke with a rotating firing order and (the second secret) if you know how to make a smaller choke make more horsepower you will be happy.

If the choke is too large in the first place, rotating-smotating (I just made that up) you won't see a difference, and so the dissimulation of mis-information and confusion continues.

A step functions to reduce flow resistance the longer a tube gets.

Unfortunately, Other things happen too.

Any sudden area change, "small" or "Large" reflect a smaller magnitude negative wave while reducing the power of the wave that continues on down the system.
They also function the opposite way to returning waves either positive or negative. They disrupt their effect, strength etc. There have been some discussions in this forum about that. Do they reduce magnitude but lengthen the durations, etc. A common term is a "reversion dam".

The "larger steps" are an attempt to combine the need to help flow and reduce the effect of returning waves. I have experimented with them a lot. Used them in Cup and Drag stuff. They are more effective in 4into1 systems than in 421's. Gee, I wonder why! 4into1 headers have stronger returning waves and the dams help minimize that problem. (I thought we were building "tuned" headers??? well, we are "tuning"out)

The merged collector with a restriction or choke is a better way to manage the pressure waves in a system in my opinion. As I have posted elsewhere a lot, in a V8 bent crank engine, the "pressure waves" in our system hurt us more than helps us. We can make more power by tuning "out" and "attenuating" the waves, which means "reducing" them or minimizing their effects.

I remember back in the 70's, Jenkins and folks used "flange adaptors" on small block chevies so they could use larger diameter tubes. The bigger tubes definitely reduced flow resistance and the "dam" created at the head/header junction functioned as a reversion dam. In a PS application with a small rpm band, it was not required. But do the same thing in a milder SB and a automatic and you have a

"dog", and the dam helps alot! but is only a weak band-aid. Many people fall into this trap. The dams are a band-aid for too large a header or collector or both. So...larger collectors=need for dams, smaller chokes=no need for dams.

What I found out early on is that doing a better job of managing waves in your system reduces the need for reversion dams. You can not use as small a choke in your final collector if you use "large steps". This I think is because we give up too much velocity and wave strength. This proved out in pro-stock as large or "Big" steps required longer primaries, even in the relatively tight rpm band. This points out how the steps slow things down and the dam created was not enough to overcome the loss of bottom end power. The merge into the choke works better when we can get more through a smaller hole. If things get lazy and weak the effects of the collector is weakened.

You start the header from the head as close in tube area to the port area. I will always step before 10" of one tube size. A 421 for 7000 rpm will want a primary about 17-18" long so you would have one step in that long a tube. The secondary will probably like to be about 1/4" larger in diameter than the primaries and the choke in the final about 1/4" again.
If you bunch the header up front as reasonably as possible that would be good as you need as much room for secondary adjustablility and also to try and get a megaphone between the final collector and the muffler. "bunching" it up more though hurts flow so there is a trade off there. Larger tube diam. to allow more "bunching" starts the swirl down the toilet of lost velocity.
That would get you started and try and allow for secondary adjustment and collector choke adjustment as that is very important for what you are doing.

In answer to the last question, I like square edges to disrupt pressure waves but flow is messed up with larger steps, but that is gonna happen anyway. The way the step it is done is not a player, mostly unquantifiable and irrelavant to your application. A lap weld or simple single tube step is a very weak weld so you will see swedged steps using butt welds but that is why they do that, it is stronger. I use a machined adapter when going past one tube step. Have Fun!

Turn off the lights in your dyno room next chance you get and see which part of the tubes gets hot first. Buckshot or whatever you want to call it the molecules are getting forced into the outside curve of any bend.

When I first started doing headers I had to pay for the tooling to get 1.88" tubing bent on a 6" radius as it was not available. I found out early enough, if you try and cram gas flow through tight radius turns you will lose flow and horsepower, this is not confusing. The same rules from the intake apply to the exhaust. I know very few people who allow a mismatch on the intake side but most people do not care at all on the exhaust.

Then there are those nice large radius exhaust ports that go up and out and flow real well on the flow bench but the chassis the motor is in requires a 2.5 or 3" radius tube off the head in order to build the header and you just reduced to worthless all the effort on the head!

Match the roof and sides and leave a step at the bottom if you have to. The best ports match the area of the intended pipe so there is no area change from port to pipe, ala there is no step anywhere! Many headers I do actually have less tube area than the port. A reduction on area from head to tube.

I think it is very important to remember, no matter what the exhaust port shape is at the end of the

casting, about 1/4 to 1/2 of an inch later in the header tube, it will be round. The less transitioning to round you have to do the better. A round exhaust port will work fine no matter what it does on the flow bench. Fancy shapes are pretty but to me are just eye candy and hurt power as I have a very hard time transitioning to round and the result is less flow!

I hope I am not re-iterating, I learned early on in Cup that any sudden area changes or even more importantly angle changes going into the header hurt horsepower. If the roof of a port is say 5degrees up to the header bolt surface and the header tube is say only perpendicular we could measure horsepower losses for just one cylinder with an offending header tube! That means a 5degree sudden angle change was measurable!

This has nothing to do with pressure wave tuning and all to do with resistance to flow by violating the same rules you would never do on the intake side!

A vast majority of engine builder-tuners and even more surprisingly cylinder head people are unwilling and at best reluctant to think beyond the flow bench and the casting itself as to the relation of port to header tube. Many will use tubes off the port on flow benches which is a good effort by those at least willing to try and quantify it. The effort is lost in my opinion as the flow bench is a miserable representation of the velocities encountered in the exhaust port, and the tubes are much more "perfect" than on the header the engine probably sees in the car.

F1 teams have used sonic flow benches, (which exist in Germany at least) and last I heard came to no conclusions or reports of learning anything. I don't believe that myself but that is racing, we will learn at sometime!

The further from the head, the more flow offenses one can get away with, but the first 8-12" of port from valve into the header is very important, not just the part in the casting! I have been doing this for over 16 years and am just now getting head porters to work with me.

For period of over 5-6 years, (about 98-2003-4) Cup engines would use a header with a 1.75" od tube off the cylinder head. The funny part is, the area of that tube was approximately 9-10% smaller than the port area at the flange surface! I am talking about championship teams here.

Using 1.75" test tubes on flow bench would hurt flow numbers and believe me, if you did not shape the transition from port to tube right, you would lose power!

Fun stuff for me and very frustrating to head porters, then and now!

I use the fact that the engine wanted the smaller tube to support my efforts to help people understand that most ports are larger than they need to be largely as a result of headers that have always been too large!

I really like when Adrian uses the term "inertia". It is the crux of the exhaust issue, IMHO, and more important than "wave" tuning. When you impart a change in the direction of a moving exhaust gas molecule, ie. the outer wall of a curve or bend or sudden area changes, some of the energy is lost from its inertia. Giving up inertia in the exhaust is not good. Giving up velocity in the exhaust is not good. The sooner in the exhaust tract you slow down the molecules the more susceptible they are to the assorted pressure waves in the tubes trying to force their direction. We do not want them to stop and

go in the other direction any sooner than possible. Everything you can do to maintain exhaust velocity is good. The further you can get the molecules away from the cylinder per event, the happier your engine will be!

I realized I want to point out here that from what I have seen, a big step is used to try and augment a area of a power curve. Real short locations, trying to boost upstairs is harder to verify and I think less effective than longer locations going after bottom end.

Also, an aspect of this big step stuff has not been addressed, so here goes. As a given primary pressure wave hits a collector, a negative wave is reflected back up the tube it came down, but the pressure wave is dispersed into the other three primary tubes as well as the exit to atmosphere. The "ugly" waves in the other three tubes are not good. The large step in a primary "mines" a certain percentage of the energy and returns is directly to the cylinder. The remainder, less powerful and so there is a reduction in the power of those bad waves in the rest of the header system. I think this is why they are more effective in helping power at slower piston speeds. They function in the same way as a 421 header, attenuating pressure waves and their effect on the other cylinders in the system. As rpms increase, the need to attenuate is less and the need to use the velocity in the collector is more important.

Another way to look at it the use is a F1 application. The rpm band they use is not amenable to the length of the tubes they have to use because of physical limitations which are several. Some may argue but at 18k rpm they can not build the header short enough to "tune" with the first reflection timing. So the big step goes in the primary at the same point they would build the header the best length. The bigger the step the more of the wave strength is used directly at the cylinder and the rest and the mass flow has a easier time traveling the rest of the distance to the body exit. Some one may want to do the math on primary optimal length for that, but I am figuring if I do NHRA PS @ 18" for 10krpm than 18krpm would want say 10"??. You will find the steps in F1 are at about 12" cause they use the step to help the bottom of the curve, I was told. Make sense?

Erland, What I would think is that if the engine wants or could benefit from a higher exhaust velocity then my answer would be no and vice versa! But why would a engine benefit from higher exh velocity? That is the question, eh?
Another thought is since the exhaust valve opens so much later, more of the cyl pressure is used to make that nice long power curve you can get with a 4v verses the 2v rather than increase exh velocity. That line of thinking would point to a smaller tube.

As we have discussed before, at higher rpm levels it is the piston speed that creates the pressure not the exh gas pressures so I see the issue as relieving pressure and not related to tube size at the end of the exh event. The better the low lift flow at exh closing the later (rpm) the pressure buildup from piston speed starts hurting intake initiation, ya? Tube size is not the real issue. The port and tubes can flow plenty when the valves are only open .1" ok? Tube sizing is relative more to the blowdown velocity and how much is getting out when valve is opening and wide open.

Recently did a header for a Comp car inline 6 with a 4valve gm head. power/Displacement is about the same as a good small block chevy. The port on the 4valve is small and used a 1.625 tube off the head! the SB used 1.88 for same power/cube. Hello? But both headers wound up at the same diameter the same distance from the cylinder, ok? But who is to say that even that was necessary. Car is competitive too, not a slouch.

And the other situation is larger tubes will probably make more power on the dyno, so...? I have stood toe to toe with Cup engine builders and asked them if they want headers that make more power on the dyno or go faster on the track. What do you think they wanted

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Blowdown pressures and corresponding velocities are declining in value after max torque, but the delta P across the exhaust valve at the end of the exh stroke keeps increasing with rpms. I have had many discussions with other folks in my circles and the piston negative displacement at EVC is a major player at elevated rpms. There is a big difference here between engines running to say 7500 (street) verses 10500 (pro-stock) and especially 18500 (F1). Tube sizing is more relative to events per second which translate into a flow issue with less tuning effect as rpm levels increase. This is in part is why F1 engines have very large tubing
for displacement, but in terms of power level the sizes are in line with slower engines. Ie, 900hp is going to need a certain size tube to exhaust the volume, no matter what the cylinder pressures, geometry or rpm.
Once again, from my corner, wave tuning is not the only player. I see the headers for the F1 people as a hindrance more than a help for them. More important to them is where they introduce the exhaust stream into the air envelope around the car! I bet if they could exhaust under the car we might see drastically different configurations. Their tubes are relatively long and large so they can get to the exit point without unacceptable losses,

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I recently had a conversation with a man who was involved for over 6 years i F1 engines. He was involved in the implementation of the large step in the headers. They just wanted to try it and when deciding "where" to put them in the system they just decided to put it half way between the engine and the collector! And then they found out that yes, if they move it around it augments the curve in logical patterns of wave tuning. Heck, I knew that back in at least 98'. lol.

It is always comforting to know that stumble technology still rules! Much to the chagrin of engineers who are now busy making sure their software can model the large steps. (just poking fun)

I always figured builders never worried about efficiencies much because most of them in my world gave up trying to measure air flow on the dyno. It wasn't untill O2 sensors became more available and running in cars as well as on the dyno that tuners actually had to deal with overscavaging. It presents the situation where the O2's tend richer and attempts to lean the system would make no change in O2's and power would drop.

I consider it a good thing for a tuner if he has time to work on things but bad if you don't. I run into it with customers quite often. The tuners ability to accept the reality of what is happening makes all the difference. Just as Larry mentioned, the Hemi was leaving a lot on the table and all it needed was a "smaller" cam to pick up bunches! Some builders have a hard time spending money on "smaller" cams.
