V8 Rover SD1 - Exhaust Systems - General Discussion.

There appear to be two commonly held viewpoints regarding exhaust systems:-

- “An engine needs back pressure to run properly!”
- “The bigger the exhaust system, the better!”

On the face of it these two are mutually exclusive, so can they both be true? Well, as it turns out the answer is, yes! However it depends on the objective of the exhaust design. The design requirements for a high revving, high power output are different to those for a low revving, high torque output.

An exhaust system carries out the following functions.

- Remove hot, noxious gasses.
- Reduce noise output.
- By design, balance both the above for optimum Cost/Efficiency trade-off.
- Reduce exhaust emissions by monitoring toxicity and controlling fuel/air mixture, or by catalytic action (modern cars only – not discussed here).

First of all, look at exhaust function from the perspective of the exhaust gases.

The piston approaches TDC and the spark plug ignites a fireball just as the piston rocks over into the power stroke. The energy of expanding gasses is transferred to the crankshaft as the exhaust valve starts to open in the last part of the power stroke. Pressure is high causing a rapid escape of gases. A pressure wave is generated as the valve continues to open. Gases flow at speeds over 350 ft/sec, but a pressure wave travels at the speed of sound (near to 1100 ft/sec, but dependent on gas temperature). Expanding exhaust gases rush into the port and down the primary manifold outlet or header pipe. At the end of the outlet/pipe, the gases and waves converge at the collector. Here they expand quickly and the pressure waves propagate into all of the available orifices including the other primary tubes. All the gases and some of the pressure wave energy flow through the collector outlet and towards the tail pipe.

So, two basic phenomenon are at work here. Gas particle movement and pressure wave activity.

- The gas pressure difference between the cylinder and the atmosphere determines gas particle speed. As the gases travel down the pipe and expand, the speed decreases. Gas particles will always try to move towards the area of lower atmospheric pressure propelled by the higher gas pressures within the exhaust system.
- The pressure waves, on the other hand, move at the speed of sound. Wave speed also decreases as they travel down the pipe, but only due to gas cooling. Wave speed will increase again as it is reflected back up the pipe towards the hot cylinder. Wave behaviour is different to gas particle behaviour when a junction is encountered in the pipe. When two or more pipes come together, as in a collector, the waves travel into all of the available pipes - backwards as well as forwards. Waves are also reflected back up the original pipe, but with a negative pressure. The strength of wave reflection is based on the area change compared to the area of the originating pipe. The speed of wave action is always much greater than the speed of gas particles.

The reflecting, negative pulse energy is the basis of wave action tuning. The basic idea is to time the negative wave pulse reflection to coincide with the period of exhaust and inlet valve overlap. The low wave pressure helps to pull in a fresh intake charge as the intake valve is opening and helps to remove the residual exhaust gases before the exhaust valve closes. Typically this phenomenon is controlled by the length of the primary header pipe.

Gas speed is also a double edged sword. Too much gas speed indicates that the system may be restrictive which hurts top end power. Too little gas speed tends to make the power curve excessively 'peaky' hurting low end torque. Larger diameter tubes allow the gases to expand; this cools the gases, slowing down both the gases and the waves.

Now the expanding gasses and noise associated with the explosions and pressure waves are rushing headlong towards the tailpipe and their sole mission in life is to upset the natives. Devising a silencing system to cope with a V8 Rover SD1 at full chat is going to depend upon an understanding of sound propagation, and the choice of available attenuation methods and materials (See later discussion).

Finally the task of tuning a system must be to accommodate the combination of primary pipe length, diameter and shape, collector method, the negative effect of silencers, plus taking account of the interference of pressure waves on each other. All this is beyond the capacity of the average owner which puts us firmly in the hands of commercial availability. But there are still choices.

So exhaust system design is a balancing act between these complex events and their timing. Even with the best compromise of primary exhaust pipe diameter and length, collector outlet sizing can make or break the best design. The goal for any exhaust system design is to create the best, most useful power curve, depending upon the application, but in the case of the V8 Rover SD1 from the viewpoint of the average driver in today's restrictive environment, low speed drivability with excellent acceleration will probably be the optimum choice, as opposed to "balls out" top speed with poor low speed drivability

Despite the theory, judgement of any design will be determined on the car by Dyno or Road testing. Exhaust designs have evolved over the years from theory, but the majority are still being built from 'cut and try' experimenting

<u>Summarising the criteria.</u>

- Header primary pipe diameter (also whether constant size or stepped pipes).
    - Despite many ideas about pipe sizing, usually the primary pipe size is related to exhaust valve and port size. Just think of it as trying to provide the smoothest possible exit route for the hot gasses with either, nil, or only smooth changes of outlet/primary pipe cross section.

- Primary pipe overall length
    - Primary pipe length is dependent on wave tuning. Typically, longer pipes tune for lower rpm power and shorter pipes favour higher rpm power.

- Collector package including the number of pipes per collector and the outlet sizing.
    - Collector arrangement is obviously dependent on the number of cylinders, the engine configuration (V-8, inline 6, etc.), firing order and the basic design objectives (interference or independence)

    - The collector outlet size is determined by primary pipe size and exhaust cam timing.

- Silencer/tailpipe package
    - Choice of silencing components gives an opportunity to go quietly, or not.

- Interference or independence tuning.
    - Interference of the pressure waves causes a slowing of gas flow.

<u>Choice of Hardware.</u>

After the air/fuel mixture burns, the leftovers consist of a variable amount of water vapour, a few unburned hydrocarbons (fuel), carbon monoxide, carbon dioxide, nitrogen oxides, sulphur dioxide, phosphorus, and the occasional molecule of a heavy metal, such as lead or molybdenum. These are all in gaseous form, and will be under a lot of pressure as the piston rushes them out of the cylinder and into the exhaust manifold. Oh Yes! I forgot! As Hot as Hell!

An exhaust manifold is usually made of cast iron. Its' primary purpose is to funnel several exhaust ports into one, so you don't need eight pipes sticking out the back of your Rover. Mmmnn! Hold that thought!!!!

Exhaust manifolds are usually quite restrictive to the flow of exhaust gas, and thus waste power because the pistons have to push on the exhaust gasses pretty hard to get them out. So, why a manifold, and why cast iron? There are two reasons. Apart from having all that lumpy metal to retain the heat, they are cheap.

The performance alternative to the manifold is a header. Where a manifold usually has several holes converging into a common chamber to route all the gasses away, a header has precisely formed tubes that curve gently to join the exhaust ports to the exhaust pipe. Not so cheap and also lots of surface area to radiate heat into the engine bay! (For a discussion regarding heat retention – see later).

The design of a solid manifold can only ever be a compromise whereas the design of a header may achieve significant improvements, yet still be limited by space and suitable materials.

Does this help? First of all, as with a fluid, exhaust gasses must flow as smooth as possible for maximum efficiency. Secondly, a header can be tuned to alter an engine’s characteristics.

So, with exhaust gases leaving the engine under extremely high pressure, it’s hard not to be aware of the noise barrage generated if they are allowed to escape to atmosphere directly from the exhaust ports. For the same explosive reason gunshots are loud, so engine exhausts are loud. It may be cool to drive around on the street with a chest-thumping 150 decibel roar, but society is intolerant to these intrusions. Hence, silencing components are introduced into the system.

Perceived Boy-Racer wisdom tells us that the right silencer design will generate more horse-power; however, any experienced Dyno technician will declare that the best silencers are no silencers at all! The Boy-Racers are only half wrong though, because a superior silencer design will lose less power that an inferior one.

Types of Silencer

Silencers can take care of their chores by three methods, absorption, restriction, and reflection; and can be designed to use one or more methods at the same time.

- Absorption is probably the least effective at quelling engine roar, but the benefit is that they are also best at letting exhaust gas through. Absorption silencers are also the simplest and utilize a construction consisting of a perforated tube that goes through a can filled with a packing material, such as fibreglass or steel wool. This is similar to simply punching holes in the exhaust pipe, then wrapping it up with insulation. The good old-fashioned Cherry Bomb would be familiar to most readers. A trickier design is a straight-through version, with a very large interior chamber where, instead of a simple perforated tube, there is a chamber inside that is much larger than the rest of the exhaust pipe. This design abates sound more efficiently than a standard straight-through because when the exhaust gasses enter this large chamber they slow down dramatically. This gives them more time to dwell in the sound insulation, and thus absorb more noise. The large chamber gently tapers back into the smaller size of the exhaust pipe, and the gasses are sent on their merry way to the tailpipe, with no loss of urgency.
- Restriction might be used in the worst OEM designs to generate noise abatement at the lowest possible cost, but restriction silencers have no efficiency advantages over other methods. To get an idea of how restriction works, place a flat hand over the tail pipe of a noisy system and note how the sound is reduced. Yet common sense tells us that the gasses can’t get away so effectively, so any restriction placed inside the system introduces a loss of efficiency.
- Reflection is used in the most sophisticated type of silencer. They often utilise absorption principles in conjunction with reflection to make an ultimate high-performance silencer. Sound is a wave, so if, by design, two waves can be persuaded to cancel each other out, all that will be left over is poison and heat. It’s not that simple of course, but you get the idea. If the outer casing is sized in length, shape and diameter in such a manner that the high-pitched engine sound (what we deem noise) is reflected back into the core of the silencer where it meets similar sounds coming the other way then it does not stretch the imagination to see how reflection might just work. If the whole lot is strategically packed with fibreglass to mop up any residual sounds then the reflection/absorbsion combination is at its most effective.

The Exhaust Pulse

To gain more understanding of how headers and silencers do their job, look at the dynamics of the exhaust pulse itself. Exhaust gas does not come out of the engine in one continuous stream. Since exhaust valves open and close, exhaust gas will flow, and then stop, then flow again as the valves reopen. The more cylinders you have, the closer together these pulses run.

For a "pulse" to move away from the engine, the leading edge must be of a higher pressure than the surrounding atmosphere. The "body" of a pulse is very close to ambient pressure, and the tail end of the pulse is lower than ambient. Indeed, enough to be approaching a vacuum! Can that be true? Well the gas rushing away from a (just) closed valve would obviously induce a lower pressure at that point. The pressure differential is what keeps a pulse moving. I’m told that a wizard experiment to illustrate this is a coffee can with the metal ends cut out and replaced with plastic lids. Cut a hole in one of the lids, point it toward a lit candle and thump on the other plastic lid. What happens? The candle flame jumps, then blows out! The "jump" is caused by the high-pressure bow of the pulse just created, and the candle goes out because the trailing portion of the pulse doesn't have enough oxygen-containing air to support combustion.

Knowing, then, that exhaust gas is actually a series of pulses, designers use this fact to propagate motion towards the tailpipe. How? Imagine that a low pressure tail end of an exhaust pulse will definitely attract the high-pressure bow of the following pulse, effectively "sucking" it along. So the first pulse is rushing away from the engine because it has a high pressure leading edge and its trailing edge is sucking the next pulse along from behind.

Within the header, the runners are specifically tuned to allow the exhaust pulses to "line up" and "suck" each other along! But this brings up more issues, since engines rev at various speeds, the exhaust pulses don't always exactly line up. Therefore the designer is forced to optimise his header design to work most effectively around the peak power output characteristics of the engine itself. In the case of a V8 Rover SD1, somewhere around 3000 to 4500 rpm.

What then might cast-iron manifolds and restrictive OEM silencer systems actually be any good for? Thinking about it, this combination would be so good at “restricting”, that in reality they'll ram the exhaust pulses together which actually enhances low-end torque because the gasses would only escape efficiently at lower repetition rates (i.e., lower rpm).

Something to keep in mind, though, is that even though such a combination may encourage globs of low-end torque, they are not the most efficient setup overall, since the engine has to work so hard to expel those exhaust gasses. At the other extreme, a header might do a pretty good job of additionally "sucking" more exhaust from the combustion chamber, so on the next intake stroke there can be lots more fresh air and fuel to burn.

Think of it this way: At 5000 RPM, your TP Vitesse is making over 300 exhaust pulses per second and there is a lot more to be gained by minimizing pumping losses as this busy time than optimizing torque production during the slow season. But the Vitesse was not intended to charge around at 5000 rpm, it had to spend most of its life burbling along at 1500 rpm, so headers were out of the question. Expressed another way, if Rover were producing an actual racing car at the time they produced a street-happy TP Vitesse, it would have had Headers rather than Manifolds.

So! Manifolds or Headers? You can still choose! And of course we do choose! Fit an aftermarket stainless steel exhaust system with gas flowed headers and chuffing great pipe diameters all the way to a 3” tailpipe, and our TP Vitesse will burn the socks off an identical car with an unmodified exhaust, when the revs are high. Now you know why! The same setup will probably be really horrible around town compared to the factory fitted option.

<u>General Rule of Thumb with Headers</u>

If there was a choice with the available SD1 headers, the best high-revving horsepower can be had with headers utilizing larger diameter, shorter primary tubes. Headers with smaller diameters but longer primaries will give slightly better fuel economy and better street driveability.

<u>Can silencers make Horsepower?</u>

The answer, simply, is no. The most efficient silencers can only emulate the same scavenging effect as a header, to help slightly overcome the loss of efficiency introduced into the system as back pressure. Because proven Dyno wisdom shows that an open exhaust system generates the most power, the introduction of both header/manifold and silencers can only degrade the available power output. So with any exhaust system the best you can hope for is a minimal loss.

<u>Pipe Sizing</u>

Returning again to the postulation that “a bigger exhaust is a better exhaust”, let’s look at the size of the pipes from a different perspective? Heat! Exhaust gas is hot, and it would be good to keep it hot throughout the exhaust system. Hot gas is less dense than cold gas, so the colder the gas the heavier it gets and therefore takes more effort to remove it from the system. Larger pipes give the hot gas an opportunity to slow down and give the gas more time to cool en-route to the tailpipe.

We don't want our engine to be pushing a heavy mass of exhaust gas out of the tailpipe and it is not just that an extremely large exhaust pipe will cause a slow exhaust flow, which will in turn give the gas plenty of time to cool off en route. Overlarge piping will also allow our exhaust pulses to achieve a higher level of entropy (Sorry! Entropy is the way energy spreads out in a process), which will take all of the hard gained header tuning and throw it out the window, as pulses will not have the same tendency to line up as they would in a smaller pipe.

If keeping the interior of the exhaust system as hot as possible is an advantage, then coating the entire exhaust system with thermal insulation material, such as header wrap or a ceramic thermal barrier reduces the cooling effect significantly. Cost may be prohibitive but a bonus side effect would be a cooler engine bay and down-pipe area.

The average owner (like me) does not have any idea of optimal exhaust pipe sizing and considering the random nature of an exhaust system, things like bends or kinks in the piping, temperature fluctuations, differences in silencer design, routing over axles, etc, make selecting a pipe diameter little more than a guessing game for anyone other than trade professionals, and even then, I doubt the best QuickVit technician would be able to tell " 'ay from a bull's foot".

Sadly then, we have to rely on perceived wisdom and the best anecdotal evidence seems to point at the following: - For engines making 150 to 250 horsepower the generally accepted maximum diameter is 3". For 250 to 350 horsepower, then 3 to 3 ½ inches is used. Over that, 4 inches is needed. If a Rover V8 ever gets up around 400 to 500 horsepower an open exhaust beckons. That should sort out the neighbours.

Having researched the above, I am left with the obvious conclusion – So What! The average V8 Rover SD1 owner still really has only two practical choices.

- Continue to use a quiet standard factory system of cast iron manifolds and restrictive mild steel components. Replace most of the components every few years due to corrosion, but get the best all round, quiet drivability that Rover intended. For a road going car. - or
- Retrofit a customised aftermarket stainless steel system of headers and (hopefully) properly designed silencers, all shiny and noisy, which will last for the lifetime of the car. It may noticeably reduce power losses within the exhaust system itself, which fools us into thinking that the exhaust system has actually added more power. Nevertheless, the result will impress drivers and onlookers alike with enhanced acceleration from the peak of the power curve on the one hand, and a crackling good exhaust note on the other.

However – for dedicated readers and avid V8 Rover SD1 aficionados – I hope this essay will make some difference to a general understanding of the Black Art of Exhaust System Design, and to the professionals out there, please let me have your comments on errors and omissions.

Ramon

Website: http://www.vintagemodelairplane.com
Blog: http://uk.blog.360.yahoo.com/maureen9235