fasttech

Words: Stewart Sanderson

BEFORE STARTING...

The first rule of working on cars and using tools of any kind is don't ever skimp on decent protection. Goggles, gloves, ear defenders, masks and a set of overalls should be in your garage. Use them.

When using power tools, protective gear is essential — grinders and welders can make a real mess of your soft skin and bone if you get it wrong.

Never work under a car without supporting it using axle stands. A car falling on you is not something you'll be laughing about down the pub.

HEAD MASTER

Pay attention as Stu offers up a masterclass in what you need to know about cylinder heads.

OVER the next few months I intend to cover some of the more old-school yet fundamental tuning processes that some modern tuners and magazines seem to have forgotten all about, since the advent of electronic tuning trickery.

I'd like to start this series with the good old-fashioned cylinder head and the various modifications we can make to it. Any good tuner will tell you that the cylinder head itself is the heart of your engine and without a good head on your block you will never get good power no matter what else you do to it, and conversely you will also never get good driveability or good fuel economy either, as these are all aspects mainly dictated by the cylinder head. The cylinder head and its associated items really do make or break the torque curve and dictate the potential power output of your engine, so let's go back to basics as always and examine why exactly the cylinder head is so important to our engine.

AIR WAYS

To describe what exactly an engine is I always find it best to compare it to an air pump. In reality, all complexities aside, that is exactly what it is — it draws air in, develops power with it after the addition of fuel, and then expels it again. This pumping cycle happens very quickly indeed, but the fact remains that the power-producing capability of the engine is directly related to its ability to pump air in great volumes, and the limiting factor to how much air can be pumped is related to the pathway into and out of the pump.

In the case of an engine this is everything from the air filter to the inlet valve, and conversely everything from the exhaust valve to the exhaust back box, but today we are dealing with the cylinder head and its associated items. So, if we increase that air volume pumping ability then we increase our potential power output. Simple isn't it?

Actually no, sadly it isn't. Although you would no doubt instantly think that this means bigger ports and bigger cams must be better, in the real world that isn't the case because various dynamics start to take their part in the proceedings and as always, things are not as simple as they first appear to be.

POWER OR DRIVEABILTY?

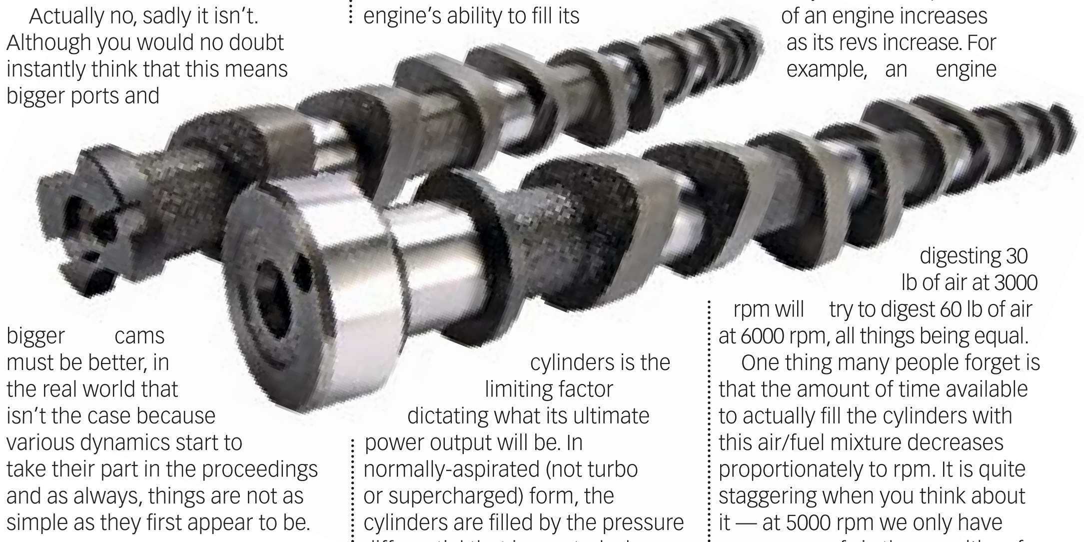
Big brash ports and cams, while often allowing the best top-end power figure, will invariable damage our low-end driveability, fuel economy and torque. Is that the result you wanted? A dog of an engine that goes OK up near the limiter but nowhere else, or did you actually want a good overall engine that goes better than standard almost everywhere and yet retains sensible fuel economy, driveability and idle characteristics?

I would say that over 90 per cent of us, myself included, want the latter, so before you take a Dremel to your cylinder head I suggest you grab a coffee and absorb a little more information on what does and does not work in the world of cylinder head porting and design. Let's look at the fundamentals.

PORT FLOW VS MIXTURE VELOCITY

We established earlier that an engine's ability to fill its cylinders is the limiting factor dictating what its ultimate power output will be. In normally-aspirated (not turbo or supercharged) form, the cylinders are filled by the pressure differential that is created when the piston moves down the bore against an open inlet valve (barring any ram or shock wave tuning effects). The actual cylinder filling efficiency is measured and expressed in terms of volumetric efficiency (VE).

The timing events of the valves opening and closing is the primary factor determining the rev range in which the engine will achieve its peak VE and where the engine will develop its peak power (see *Fast Ford* issues 245 and 246 for more in-depth camshaft and timing information). Don't forget that the airflow capability of the head and the velocity of the airflow itself are all factors that are taken into account when designing camshafts, so be aware that modifying the head too much can also mean the camshaft is no longer suitable.



AIRFLOW REQUIREMENTS

Naturally the flow requirement of an engine increases as its revs increase. For example, an engine digesting 30 lb of air at 3000 rpm will try to digest 60 lb of air at 6000 rpm, all things being equal.

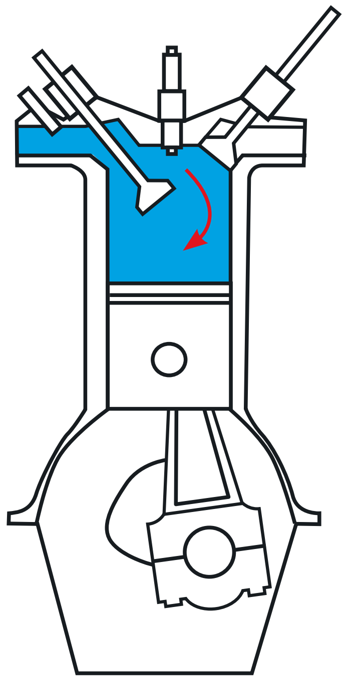
One thing many people forget is that the amount of time available to actually fill the cylinders with this air/fuel mixture decreases proportionately to rpm. It is quite staggering when you think about it — at 5000 rpm we only have an average of six thousandths of a second to get the air into the cylinder before the valve closes again. Once the engine's airflow demand outstrips the ability of the head to deliver increased airflow, VE tails off, as does peak power.

As a quick example, if a head can flow 30 lb of air per minute and the engine at 3000 rpm requires 30 lb of air per minute it will make 100 per cent volumetric efficiency here and possibly its peak torque, but be

Having massive inlet ports can actually lose you power, as it slows down speed of the airflow

aware that the same head will only supply 30 lb of air per minute to the engine, which at 6000 rpm requires twice as much to make the same torque as it did at 3000 rpm. All of these airflow issues are dealt with by the cylinder head (obviously ignoring any inlet hardware restrictions that may exist such as throttle body, airbox etc).

So we know that large amounts of airflow are paramount to high engine speed performance and thus high bhp output. However, if



An engine's ability to fill its cylinders dictates what power it will produce

achieving large flow figures was all that we needed to create a good-quality cylinder head, port design would not represent a significant engineering challenge at all. We would simply bore in some huge drainpipe-sized inlet and exhaust tracts and fit massive combustion chamber-filling valves.

This would create an engine that was useless, it's unlikely it would even start and idle. Why? Because velocity is as important as volume.

INLET VELOCITY

It's a sad fact that as port volume increases, velocity decreases. A huge port between the throttle body and the inlet valve will create a proportionally large volume of air. The actual motion of air through the inlet tract to the cylinder is dictated by the volume of the cylinder made available by the piston moving down the bore. So the nearer we get to matching the two volumes up, the slower our gas speed will be on the cylinder filling event.

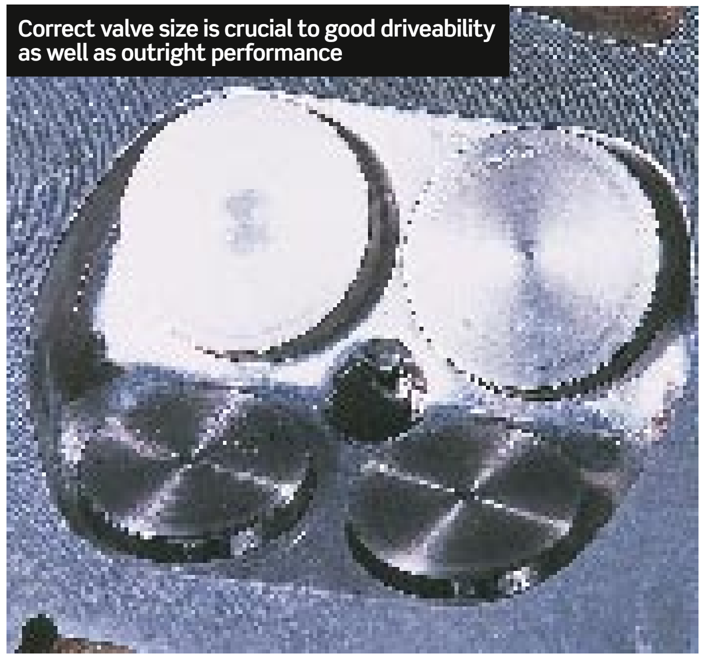
As an example, imagine the same scenario using a pint glass and a straw. You have 3 seconds to fill the pint glass from a tap using a straw. The speed the water travelled through the straw to the glass would be very high. However, if you perform the same test but use a hose pipe to fill the glass, the actual speed of the water would be a lot lower, due to shifting far more volume per second. It's the same principle in an engine, but we are talking thousandths of a second, so the speeds are far higher.

It's also important to know that since the large column of air in the inlet tract is the only means by which the cylinder communicates with an engine's MAP sensor or airflow meter, a large, lazy volume of air in the port is slow to provide a signal to your management about what exactly is happening and what our fuel requirements are. The end result of this is a lazy throttle response and an engine that feels flat. Conversely, a high port velocity means that the air column is moving faster and this means information will be relayed more accurately to the management. Far more important than this is a totally different dimension that has now opened up to us — gas inertia.

INLET GAS INERTIA

Basic physics tells us that a body in motion (in this case, the air column) will build momentum and will want to keep moving in the same direction, even as the force acting on it is removed. It's called inertia.

In the case of the air within the port, the force acting on the air column is the pressure differential in the cylinder as the piston moves down and the pressure acting upon it from the atmosphere. When the piston slows as it reaches the bottom of the cylinder at the end of the induction stroke, good port velocity is helpful



Correct valve size is crucial to good driveability as well as outright performance

to continue filling the cylinder, cramming in the air, sometimes above 100 per cent VE as we actually compress some air due to the piston moving upwards and the gas still travelling downwards when the intake valve closes.

A good example of inertia is when we spin a heavy wheel, maybe on a car or push bike. Once we have let go after our spinning movement, the wheel takes no more energy to continue spinning, so it should have just stopped when we let go, but it didn't, did it? In fact, if we try to stop it spinning now it resists us. This is inertia.

EXHAUST GAS VELOCITY & INERTIA

In the exhaust port, many of the same considerations apply as with the inlet ports. In the exhaust ports, instead of drawing in air and fuel to fill the cylinder we are actually pushing it out with a piston. Maintaining a good gas velocity here helps to scavenge the cylinder of spent gases to promote good cylinder filling of fresh air/fuel charge, because don't forget we cannot fill a cylinder with 100 per cent fresh fuel and air, if 15 per cent of the old burnt garbage is still in there, can we?

If we look at an exhaust port with poor flow velocity due to excessive port size, we will see that we will usually have a large, slow-moving pocket of burnt gas literally slowed down to almost stationary awaiting the next push of gas to shove it into the manifold. Why? As the piston reached the top of the exhaust stroke and then began to slow massively ready for its direction change, the lack of inertia in our gas (due to the large port) meant the mixture also stopped and in some cases, it can actually reverse direction and flow backwards as the inlet valve is open at this point allowing sometimes less pressure in the cylinder than the exhaust port (a gas will always flow to the point of least resistance). This is not at all helpful as it dilutes our incoming fresh mix. This effect is usually far worse at low rpm where flow rates and velocity are at their lowest due to obvious factors.

It's worth bearing in mind that this particular issue is normally made far worse with increased-overlap, high-performance cams. The result is an engine that is slow to get on the cam as engine speed picks up some velocity in the exhaust port, and very poor low-speed engine operation and bad, sometimes non-existent idle.

Ultimately, both the intake and exhaust ports must balance flow velocity and flow capacity to achieve flexible performance over a broad range of engine speeds. This is a necessity in a road-based performance engine. We should always maximize the efficient use of the port to achieve the required gasflow, instead of simply making bigger ports to give ultimate high-end bhp.

SWIRL & TUMBLE

After dealing with the port's flow capacity and of course velocity, the next logical step is to recognise the presence of externally-induced mixture motion. The important part here is to recognise the fact that the mixture will flow through the port and into the cylinder in a very un-uniform fashion, and will normally enter in a rotational fashion.

This is best compared to a plug and drain in a sink. When you pull the plug, the water in the sink doesn't just pour down the plug hole and out of the drain like it was poured from a pan does it? No, because it also has to flow down a port of sorts, it exits in a rotational motion following the perimeter of the bore.

Tumble is a little harder to put into words, but imagine pouring a liquid quickly into a wine glass down one side, and the liquid quickly rises up the opposite wall of the wine glass then almost free falls into the centre of the glass, this is what I call port tumble.

Many factors can influence tumble but the most dominant factor is the intake valve's position in the combustion chamber when looked at in relation to the intake port's centreline. Many older combustion chamber designs that placed valves around the perimeter of the chamber induced mixture tumble. Modern inline valves tend to promote far more swirl, which, overall, is far better.

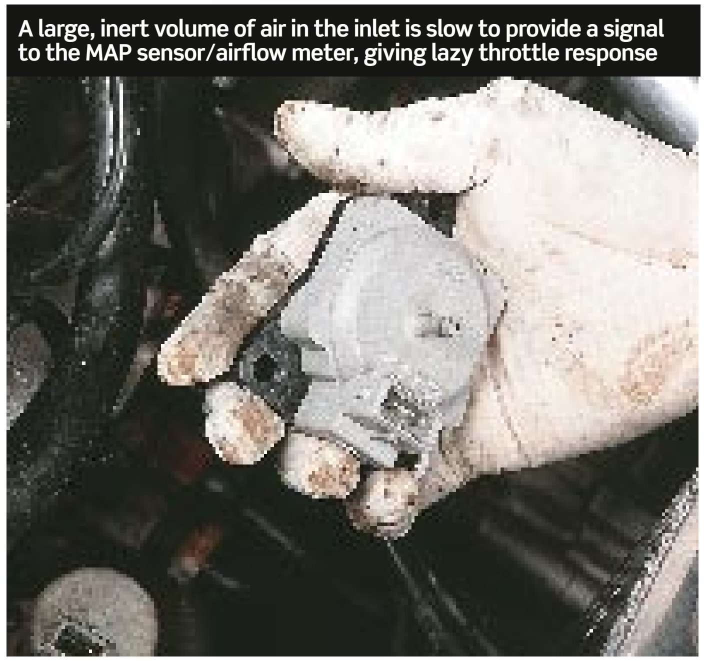
SQUISH EFFECT

Something I have seen badly modified many times over the years is the squish area of the cylinder head. It has often been destroyed by someone who quite possibly doesn't even know that it exists, let alone what its purpose was. Squish is the term used to describe the area of the cylinder head that comes into very close proximity to the piston at top dead centre (TDC).

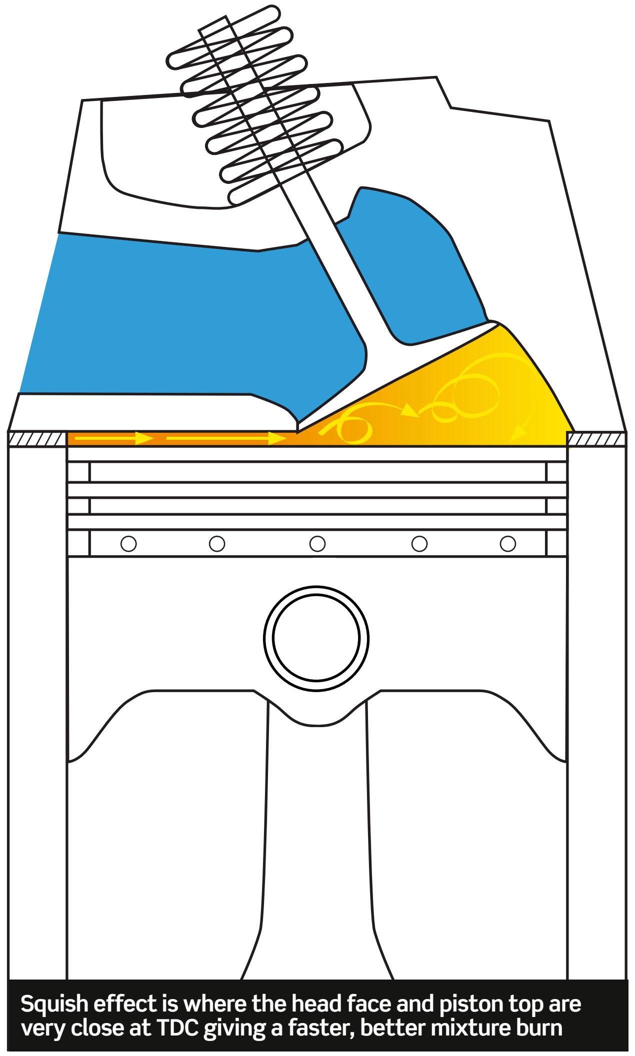
It's a known fact that in over 90 per cent of engines, a faster burn and a more turbulent mixture are obtained when the compression height of the piston is set to take the maximum advantage of the flat quench face of the cylinder head.

In other words, if the area between the flat face of the head and the piston top is sufficiently close, as the piston reaches TDC on the compression stroke, the mixture that occupied the area over the piston is forced at high speed into the direction of the advancing flame front. The benefits of this are faster burn and greater turbulence at the time of combustion. This is called the squish effect. In a nutshell, the fuel/air mixture at the outer edges of the combustion chamber is literally squished into the centre of the chamber by the rising piston.

A second benefit of this squish phenomenon is that the engine's mechanical resistance to detonation is improved when close piston-to-head clearance is utilised.



A large, inert volume of air in the inlet is slow to provide a signal to the MAP sensor/airflow meter, giving lazy throttle response



Squish effect is where the head face and piston top are very close at TDC giving a faster, better mixture burn

Detonation almost always begins in an area other than that where the main flame front is initiated. With a flat-topped piston, the area opposite the spark plug in the quench area is prime detonation territory. If this area is sufficiently tight, the ability for it to detonate reduces since the combustion at the desired flame front occurs quicker due to the squish effect and lessens the time for heat rise in the mixture at the far end of the chamber. Furthermore, the thin section at the squish area exposes only the small volume of mixture to an equally high surface area, diminishing the heat rise in this part of the mixture.

THEORY TEST

So, there you have it, I hope that has given you a small insight into what goes into the modifying of a cylinder head, or at least the theory behind the modifications and why you cannot simply take a Dremel to a cylinder head and make everything bigger as many home tuners do.

WHAT IS VE?

This is the ratio between the mechanical volume available within the cylinder, and the volume of mixture the cylinder actually ingests. For example, if the cylinder is completely filled with fuel/air, the volumetric efficiency is 100 per cent. If it is only 70 pe cent filled with fuel/air we say the engine at that point has a volumetric efficiency of 70 per cent.

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CAN WE DIY?

Removing casting marks from the ports is well worth doing

The previous pages cover the majority of the key elements that need careful consideration before you start boring out your cylinder head and fitting the biggest valves known to man.

So what can you do on a DIY level that will improve things before you have to give the head to a professional? Well, basic cylinder head porting will improve the performance of any production cylinder head by simply removing the flaws that are present due to the procedures used to manufacture these large castings in a mass-production environment. Most of the work in a basic porting project is focused on reducing the restrictions and compromises have to be made with:

CASTING MARKS AND RIDGES

These are present on port floors, roofs and walls and are caused by the casting process. Such items ruin the smooth flow of gas and create turbulence and swirl as well as taking up precious room in the tract. A simple flap wheel can often remove these issues to a suitable standard.

STEPS FROM MANIFOLD TO TRACT

These steps are simply there due to a mismatch in port size and manifold size or position, and it's well worth matching the two up so the flow from manifold to head (see pic on the right), or indeed head to manifold on the exhaust side, is restriction and obstacle free for your high-speed gas. A Dremel with a decent cutter is needed here, and of course you need to be very careful not to cut too much out or break a waterway or oil gallery. If you do, the head is scrap.

Removing sharp edges in the valve guide boss and seat areas speeds up airflow

SHARP EDGES

These can be found in the valve guide boss area and in most cases the top of the valve seat areas. Sharp edges create large amounts of turbulence as they work just like a ramp to the high-speed air, forcing it to tumble and crash into walls, slowing its progress massively. All areas should be nicely radiused for maximum smooth progress of the high-speed gas.

CASTING ROUGHNESS

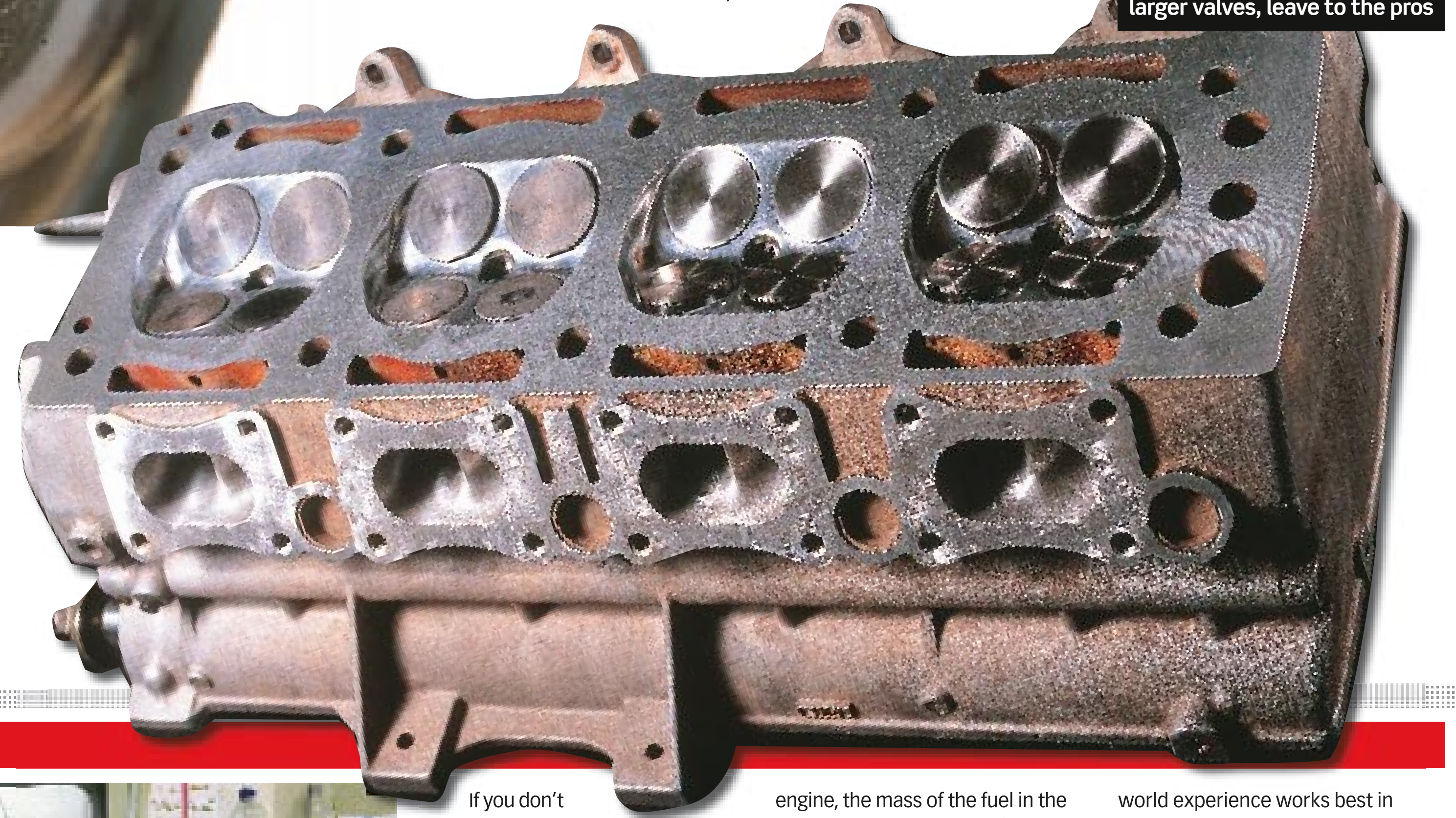
The castings on an OEM head will be quite rough, and its worth cleaning them up so they become smoother. A mirror finish is pointless and can in fact be detrimental on the inlet side, but a good smooth finish on the exhaust ports can be beneficial in resisting carbon build up which does of course slowly cut down our available port flow.

BASIC PORTING

Whilst very time consuming, basic porting isn't actually hard work. I would allow around 8 hours for an average DIY mechanic to do a decent job on the average four-cylinder, 16-valve head and thus produce a decent head with no nasty casting marks, burrs lumps or sharp edges to ruin our gas flow.

Please remember, a basic porting job does not attempt to correct any design or engineering deficiencies present in the casting itself, and is intended purely to improve upon the existing design without really changing anything dramatic.

As soon as you try to change the way things work in a large way, such as changing port angles or changing valve sizes, you really are beyond the scope of a DIY basic head port and should be enlisting the help of professionals who do this for a living.



You can do basic head mods yourself. But stuff like fitting larger valves, leave to the pros

TESTING

Dyno testing is the only sure-fire way to find out if your head mods have worked

If you don't test on a dyno you will never really know what gains you have made, or indeed where you have lost out. A flow bench is ideal to study and test what you have done to the airflow characteristics, but any professional with flow bench and dyno experience will tell you that once you bolt it onto an engine it all means very little anyway as flow bench data often doesn't relate to engine performance in any way shape or form.

Beyond frictional flow losses, other factors affect airflow in an engine and cannot be duplicated by flow bench testing. These are air density, thermal transfer of heat to the incoming charge from the engine, the mass of the fuel in the air, your piston crown configuration, the rod/stroke ratio, the piston velocity, engine rpm and intake manifold tuning characteristics, to name only a few.

This does not discount the validity of flow testing and with some simple mathematical equations, an accurate prediction of engine performance can be derived from it, but never assume the flow bench has proved your head will work, often what a perfectly educated man thinks is right will prove to be totally and utterly wrong.

Airflow still hides itself very well behind a mask of invisibility and even the motor manufacturing giants' own scientists still struggle to get their head ports right. Real-world experience works best in this arena and that's why I suggest beyond a basic port clean-up you entrust your head to a pro with a lot of experience with your particular head.

NEXT MONTH

Vital knowledge about exhaust manifolds and systems

CONTACT

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